DESERT RESEARCH INSTITUTE
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Final Report

ASSESSMENT OF THE SALINITY TOLERANCE OF EIGHT SONORAN DESERT RIPARIAN TREES AND SHRUBS

USBR Contract No. 9-CP-30-07170

Submitted to:

U.S. Bureau of Reclamation
Lower Colorado Region
Yuma Projects Office
Yuma, Arizona

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September 10, 1990

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ACKNOWLEDGEMENTS

The authors thank Patricia Moen, Valerie Yturiaga, and William Katchske for their technical contributions in both greenhouse and laboratory; and Julie Muhilly and Barbara Nauroth for production of the final report. Gary Ferrier and Jim Rorabaugh of the U.S. Bureau of Reclamation Yuma Projects Office are gratefully acknowledged for their technical assistance.

ABSTRACT

Eight species of Sonoran Desert riparian trees and shrubs were examined in a greenhouse-based study of salinity tolerance at six levels; 0; 1,500; 6,000; 18,000; 36,000; and 60,000 mg/l. Analysis of percent survival and morphological growth response indicated that two of the eight species, *Populus fremontii* and *Salix gooddingii* exhibited no tolerance above 1,500 mg/l. *Tessaria sericea* was intolerant of salinity levels of 18,000 mg/l and above. *Atriplex lentiformis* and *Tamarix chinensis* exhibited significant growth decreases at 36,000 and 60,000 mg/l. *Prosopis juliflora* var. *torreyana*, and *P. pubescens* growth responses were not readily detectable because growth under experimental conditions was slow. Indications of salt tolerance were observed in *Allenrolfea occidentalis* growth response, and the data suggested greater growth response at intermediate salinity levels. Laboratory measurement of spectral reflectance of leaves suggested that salt stress was discernable through examination of the location of the "red edge" of the electromagnetic spectrum, and that measurement of reflectance may provide a predictor or indicator of salinity stress. Measurement of photosynthesis show that salinity clearly reduces the rate of carbon gain in all studied species. Technical problems will have to be overcome before measurement of photosynthesis will be a useful tool for detecting salinity damage in the field. Measurements of chlorophyll fluorescence indicate that under field conditions differences in this parameter are unlikely to appear in relation to salinity stress.

INTRODUCTION

A serious problem related to plant growth in arid regions is the accumulation of salt in soil (Kramer 1983). Whereas salts in humid soils are leached by continuous precipitation, arid zone soils accumulate high salt content through the processes of evaporation and upward capillary movement of moisture from the water table. Irrigation practices which leach soil salts and drain salt-laden water into rivers contribute to downstream soil salinity. Introductions of phreatophytes such as *Tamarix chinensis* (salt cedar) and *Phragmites australis* (reed) further contributed to soil salinization through groundwater and soil water consumptive use.

On the lower 276 miles of the Colorado River from Davis Dam to the Mexican border, soil and water salinity fluctuate as a function of water diversion, evaporation, and salt loading. Salt concentrations are expected to increase without control measures, some of which are presently being implemented to control contributions from various sources (USBR 1989). These increases, as well as other water use practices such as upstream diversions, impoundment, channelization and vegetation clearing have had dramatic effects on the species composition and structure of riparian vegetation of the lower Colorado River.

BACKGROUND

The lower Colorado River encompasses some 276 miles of riparian floodplain in the lower Colorado subdivision of the Sonoran Desert.

Prior to impoundment and channelization of the mainstream Colorado, the dominant riparian tree species of the lower terraces included *Populus fremontii* (Fremont cottonwood) and *Salix gooddingii* (Goodding willow). Shrub species associated with these riparian forest dominants included *Tessaria sericea* (arrowweed), *Baccharis glutinosa* (seepwillow), and occasionally *Prosopis pubescens* (screwbean mesquite. On the upper terraces, plant associations adapted to drier conditions were predominant. Major species present on the upper terraces included *Prosopis juliflora* var. *torreyana* (honey mesquite), *Atriplex lentiformis* (quailbush), and *Suaeda torreyana* (inkweed) (Ohmart et al. 1989).

In recent years, the composition of riparian vegetation along the lcwer Colorado River has changed significantly from that of the period of pre-river control. While native vegetation associations still exist along the River, the introduction and establishment of the exotic and invasive *Tamarix* in the years following river damming and channelization resulted in dramatic changes to the species composition and dominance of riparian plant associations along the lower Colorado River. *Tamarix* has established a permanent position in the riparian zones of many southwestern streams and rivers; a function of its tolerance, relative to native species, to factors such as prolonged drought or inundation, fire, and soil salinity (Robinson 1965, Warren and Turner 1975, Everitt 1980).

A number of factors are responsible for the overall decline of native vegetation and associated alteration of riparian vegetation associations along the lower Colorado River. Foremost among these factors was the loss of the natural spring flood regime which provided adequate moisture and leaching functions necessary for cottonwood regeneration. Also, fluctuating river and soil salinity affected edaphic conditions within portions of the floodplain (Ohmart et al. 1988).

Various Federal and State efforts to revegetate the riparian floodplain have occurred since the late 1970s, in effort to mitigate for losses of native riparian vegetation along the lower Colorado River. A primary goal of many of these efforts was to restore wildlife habitat, thus revegetation plantings frequently included native species of high wildlife values such as *Populus*, *Salix*, *Prosopis* spp., and *Atriplex* spp. Approximately 20 major revegetation projects have been implemented since the late 1970's, however, there have been more failures than successes. Primary reasons for project failures include poor planning, lack of monitoring, and failure to initiate project improvements when needed (Carothers et al. 1989). However, other failures are clearly a function of knowledge gaps in the limits of plant tolerance for adverse environmental conditions such as salinity.

OBJECTIVE

The objective of this investigation was to determine the salt tolerance of eight lower Colorado River riparian trees and shrubs (Table 1) through a greenhouse and laboratory

based study of germination, growth, survival, and physiological response to salinization. Our primary goal was to monitor the response of eight species, in both seedling and seed germination stages of growth, to six irrigation water salinity levels: 0; 1,500; 6,000; 18,000; 36,000; and 60,000 milligrams per liter (mg/l). These salinity levels were pre-determined by U.S. Bureau of Reclamation (Reclamation) personnel, and represent the range of salinity conditions which might be expected to occur in the soils of the riparian floodplain along the lower Colorado River through processes such as inundation, recession, and evaporation of salt-laden surface waters; dissolution of soil salts; and capillary movement of saline groundwater into the riparian root zone.

Table 1. Eight species of Sonoran Desert riparian trees and shrubs evaluated for salinity tolerance

Scientific Name	Common Name
Atriplex lentiformis (Torr.) Wats.	Quailbush
Allenrolfea occidentalis (Wats.) Kuntze	Pickleweed
Prosopis juliflora (SW.) DC var. *torreyana* L. Benson	Honey mesquite
Prosopis pubescens Benth.	Screwbean mesquite
Salix gooddingii Ball.	Goodding willow
Tamarix chinensis (Lour.)	Salt cedar
Tessaria sericea (Nutt.)	Arrowweed

The study included an evaluation of salt tolerance as exhibited by physiological as well as morphological plant response. While morphological response to salt stress provides readily obvious growth responses, i.e. growth rates, mortality, and biomass productivity; physiological response is not immediately apparent. The effects of stress on physiological functioning generally occur long before salt stress has a measurable effect on plant growth (Smillie and Nott 1982). This investigation thus included an experimental approach for detecting the precursors to reductions in plant growth and productivity. Three types of physiological measurements were measured: spectral reflectance, photosynthesis, and chlorophyll fluorescence.

METHODS

Part 1: ANALYSIS OF SEEDLING GROWTH AND SURVIVAL

Experimental Design and Greenhouse Layout

The analysis of seedling growth and survival was conducted in greenhouse facilities located at the University of Nevada, Reno. Experimental operations commenced on June 15, 1989 and continued through July, 1990. The morphological plant growth experiments were conducted during the period September 7, 1989 through January 3, 1990. Additional physiological measurements were conducted on new plants grown during the period January through July, 1990.

Controlled greenhouse conditions eliminated the potential for wide ranging environmental conditions among or between treatment groups, and utilization of a randomized block experimental design provided further control for possible differences in temperature, light, and humidity within the greenhouse setting. The greenhouse experimental design consisted of ten "blocks" of 48 plants each (twelve rows of four containers). Each block was further characterized by six "groups", consisting of one of each of the eight species. Each of the six groups within each block were watered with one of the six different salinity treatments.

The irrigation system consisted of six, 500-gallon capacity polyethylene tanks connected to a Grainger one third horsepower corrosion resistant, submersible pump controlled by two sets of solenoids. The first set of solenoids regulated the flow of irrigation water from the irrigation tanks; the second set regulated the flow into the irrigation system. Flow to the individual plants was attenuated by Chapin tube/weight type (0.076 tube diameter) emitters.

The irrigation system ensured delivery of a total of 2 gallons of solution per day to each individual plant. The system was controlled by two, six-zone control Lawn Genie Ultra Electronic Sprinkler Timers. One timer controlled the overall sequential flow of irrigation solution to the plants. The other timer provided a mechanism to back flush the residual solution out of the system, preventing salt build-up in the lines. Both timers were

equipped with back-up power supplies. The system was checked daily for leaks, clogging, and proper electrical functioning in order to ensure uniform daily water delivery throughout the duration of the study.

Six different salinity levels were achieved by dissolving 100 percent industrial grade, fine sodium chloride (NaCl) and 90 percent calcium chloride ($CaCl_2$) mini-pellets into the tanks. Salts were added in a ratio of 1:1 for the first 16 days of the salinization period; and in a ratio of 3:1 there after. Plantex fertilizer (20-20-20 + micronutrients) was added to each irrigation solution at a ratio of 171 gm per 100 gallons (one-sixteenth strength of the standard solution).

Cuttings and seeds for each of the eight experimental plant species were collected along the Colorado River in the vicinity of Yuma, Arizona on June 14, 1990. Seeds of *Populus* and *Salix* were unavailable at this time. Seedlings from cuttings were established by dipping the freshly cut bases in Rootone hormone, and rooting them in pre-moistened 100 percent perlite. Seedlings from seeds were established by sowing in pre-washed #30 mesh Monterey Sand. Both cuttings and seeds were watered under a mist regime (15 seconds every 10 minutes) until rooted. Attempts were made to cultivate seedlings from seeds for the six species for which seeds were available, however, the final choice on propagule type was based on the overall vigor of the seedlings and cuttings after the initial establishment phase. Rooted cuttings were ultimately used for *Atriplex*, *Populus*, *Salix*, and *Tamarix* and germinated seeds were used for *Allenrolfea*, *P. juliflora*, *P. pubescens* and *Tessaria*.

The established seedlings and cuttings were transplanted between July 24 through September 7, 1990 to five gallon, polyethylene pots containing leached filter sand. This hydroponic sand culture system provided leaching and drainage capability sufficient to prevent excess salt build-up. Each container was coded for identification with colored tags and numbers. The cuttings were irrigated with a non-saline water supply, fortified with one-sixteenth strength Plantex (20-20-20 plus micronutrients) fertilizer for 30 days prior to the onset of salinization in an effort to avoid transplant shock.

The ultimate planned salinity level for each group was, to the extent practical, achieved gradually over the first month of the experiment. Table 2 indicates the schedule of gradual salinity increases over the first 30 days of the period of salinization.

Table 2. Schedule of planned, gradual salinity increases during Days 0-29 of the period of salinization

Days After Salinization	SALINITY (mg/l) (Final Concentration)					
	0	1,500	6,000	18,000	36,000	60,000
0	0	1,500	1,500	1,500	1,500	1,500
0	0	1,500	1,500	1,500	1,500	1,500
3	0	1,500	3,000	3,000	3,000	3,000
5	0	1,500	4,500	4,500	4,500	4,500
8	0	1,500	6,000	6,000	6,000	6,000
10	0	1,500	6,000	9,000	9,000	9,000
12	0	1,500	6,000	12,000	12,000	12,000
15	0	1,500	6,000	18,000	18,000	18,000
17	0	1,500	6,000	18,000	24,000	24,000
19	0	1,500	6,000	18,000	30,000	30,000
22	0	1,500	6,000	18,000	36,000	36,000
24	0	1,500	6,000	18,000	36,000	45,000
26	0	1,500	6,000	18,000	36,000	54,000
29	0	1,500	6,000	18,000	36,000	60,000

Other procedures and practices were implemented to control adverse conditions potentially affecting plant growth. The irrigation tanks were covered with black polyethylene plastic to preclude algal growth. Daily application of incandescent lighting between 1600 and 2000 hours was commenced in mid-September, 1989 to prevent dormancy among the experimental plants. Pest control was initiated at infrequent intervals throughout the duration of the experiment to offset the deleterious effects of aphid and mite damage. Aphids were initially controlled by Safer's Insecticidal Soap, and later replaced by a systemic pesticide (Systox), which proved more effective in preventing plant damage.

Data Collection

Morphological and physiological data were collected to monitor the plant growth response during the period of salinization (Table 3). Morphological data collection included percent survival, root and shoot biomass, cumulative shoot length increase (stem elongation), and leaf area measurement. Number of surviving individuals was recorded on a weekly basis and converted to percent survival by species and salinity. Biomass measurements were taken at the end of the salinization period, by separately harvesting the root and shoots of each plant, drying to a constant weight at 60 °C, and weighing to the nearest gram. Root/Shoot ratios were calculated for each individual. Stem lengths were measured weekly on the major growing stems to estimate cumulative shoot length increase. Mean leaf surface area and total leaf surface area were determined for surviving individuals in each experimental group.

Statistical Methods

Descriptive statistics were calculated for each variable by species and salinity level to characterize their probability distributions. Measures calculated include the median, standard error of the median, variance, skewness, kurtosis, range, minimum and maximum. Because many of the sample sizes were relatively small and their distributions sometimes departed from quasi-normality, a non-parametric exploratory data analysis approach using robust and resistant measures and graphical techniques was also adopted.

Box and Whisker Plots

Box-and-whisker diagrams (Tukey 1977, Velleman and Hoaglin 1981) are used in this report to visually depict the data sets by showing the maximum, the minimum, three quartiles of the data, outliers, and approximate simultaneous 95 percent confidence intervals about a set of medians. The box-and-whisker plots portray considerably more information about the distribution of values of a variable than commonly used parametric graphic displays including the mean and standard deviation, which may not be particularly good indicators of central tendency and dispersion if a distribution has non-normal

Table 3. Growth variables analyzed during the investigation of riparian seedling growth and survival

Variable	Acronym
Root biomass (grams)	Root
Shoot biomass (grams)	Shoot
Root/Shoot Ratio	R/S
Cumulative stem growth 30 days after salinization (cm)	Day-30
Cumulative stem growth 60 days after salinization (cm)	Day-60
Cumulative stem growth 90 days after salinization (cm)	Day-90
Cumulative stem growth 120 days after salinization (cm)	Day-120

tendencies. Figure 1 illustrates a sample box-and-whisker plot. Three points called quartiles divide the data set into four quarters: the first quartile (Q1), is a point such that at least 25 percent of the measurements are at or below it and approximately 75 percent of the measurements are above it. The second quartile (Q2), corresponds to the median, which divides the measurements into two equal parts, and; the third quartile (Q3), is a point such that 75 percent of the measurements are at or below it and approximately 25 percent of the measurements are above it. The median at the center of the notch divides the data into two halves. The edges of the 'box', called the lower and upper hinges, split the remaining halves in half again.

To understand the rest of the plot, a few terms need to be defined: h-spread, inner fence and outer fence. The h-spread is the interquartile range, which is the absolute value of the difference between the upper (Q3) and lower (Q1) hinges, and is a measurement of dispersion of values about the median. Endpoints of the whiskers, or inner fence, which are the vertical lines extending above and below the 'box' (equivalent to 1.5 times the h-spread), extend beyond the upper and lower hinges. Endpoints of the outer fence, not shown on the plot (equivalent to 3.0 times the h-spread) extend beyond the upper and lower hinges. Values lying between the inner and outer fences are shown with asterisks.

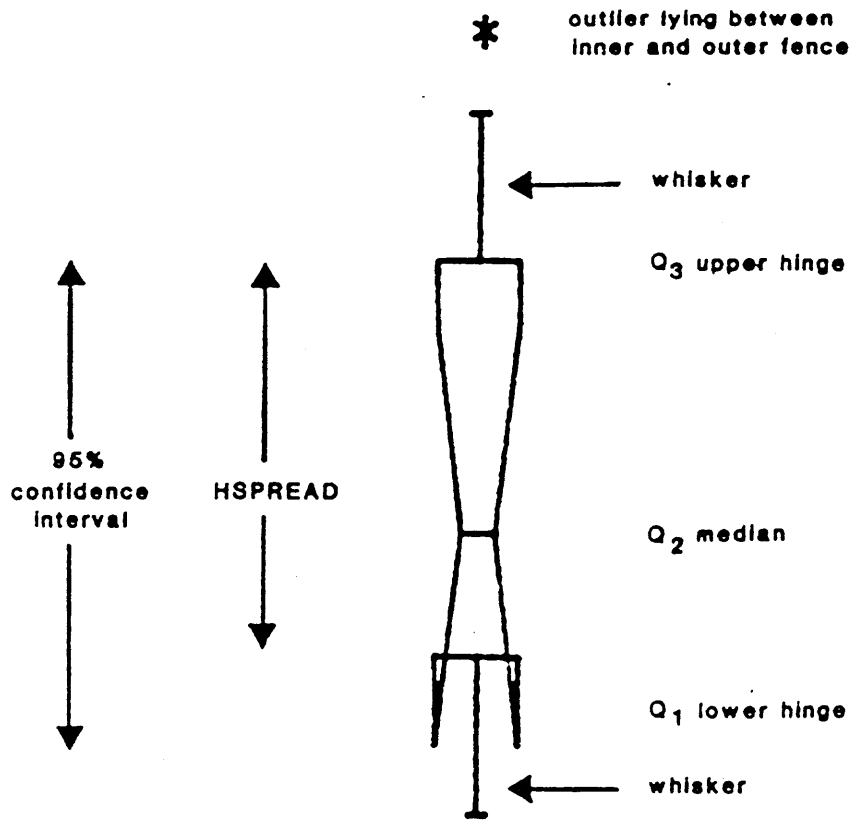


Figure 1

Sample Box-and-Whisker diagram illustrating the salient features described in the text.

Values lying outside of the outer fences are not illustrated. Frequency of occurrence of outliers for each species and growth variable are provided in Table A-1 of the Appendix.

In the box-and-whisker diagrams, simultaneous confidence intervals about the medians are implemented at approximately the 95 percent confidence level, following the discussion of McGill et al. (1978). Boxes are notched at the medians, as mentioned above, and return to full width at the upper and lower confidence interval values. If confidence intervals about two medians do not overlap, one can be reasonably assured at about the 95 percent level that the two population medians are different. In some cases the confidence limits extend beyond the hinges (for example, the lower hinge of Figure 1). While unaesthetic, it adheres to Tukey and McGill's original standard for this type of plot.

Analysis of Variance (ANOVA)

Seedlings used in this experiment were randomly assigned to the six salinity treatment groups to create a randomized block experimental design. This design is appropriate for examining each species differences in growth response to the salinity treatment. Analysis of variance (ANOVA) for a fixed effects model (Zar 1984) was conducted to simultaneously examine the effects of the six different salinity treatment levels (the independent variable) on growth and physiological measurements (the dependent response variables) obtained during the experiment.

The null hypothesis tested with the ANOVA is that the population means of a particular dependent variable are equal across salinity treatments. Failure to reject the null hypothesis at a significance level of 0.05 indicates that values of the dependent variable do not differ with salinity treatment. For example, cumulative shoot growth of *Atriplex* measured on Day-30 (see Figure 3d and Table 7) is an example where the null hypothesis is accepted. The probability (0.148) associated with the F-ratio of 1.712 with 5 and 53 degrees of freedom is considerably greater than the critical value of 0.05.

Rejection of the null hypothesis indicates that a significant difference exists among the means of a response variable across salinity treatment (e.g. *Atriplex* shoot biomass, Fig. 3b, Table 7). The F-ratio for this example, 5.757 with 5 and 48 degrees of freedom, has an associated probability less than the critical value of 0.05. However, at this point in the analysis it is unknown which specific pairs of means differ significantly.

Tukey HSD Multiple Comparison Test

Tukey's Honestly Significant Difference (HSD) Test, an a-posteriori multiple comparison test for pairs of means, was used to ascertain which mean differences are significant. This type of test, adjusted by a harmonic mean (Tukey-Kramer version of the test) was applicable for the experimental data collected in this investigation since it can be applied to unequal cell counts resulting from plant morphology throughout the experiment (Miller 1985). The pairwise absolute mean differences in the *Atriplex* shoot biomass example mentioned above are listed in Table 7. This table shows significant differences in shoot

weight between salinity levels 6,000 and 36,000 mg/l; 6,000 and 60,000 mg/l; 18,000 and 36,000 mg/l; and 18,000 and 60,000 mg/l.

Spectral Reflectance

Reflectance spectra of green leaves were measured in the laboratory to determine the potential utility of using remotely sensed vegetation reflectance values to determine salinity stress in riparian vegetation. Spectral reflectance curves indicate light energy reflected from materials as a function of wavelength.

Figure 2 illustrates a typical spectral reflectance curve for green vegetation as a function of wavelengths between 400 and 800 nanometers (nm) on the electromagnetic spectrum. Vegetation reflectance is particularly diagnostic along the "red edge" of the spectrum, i.e. the transition between red and infra-red wavelength bands, where the reflectance curve climbs steeply in response to increasing reflectance of infra-red light by chlorophyll (Figure 2). In general, decreased chlorophyll content in response to environmental stress such as salinity will result in a shift of the "red edge" of the reflectance curve. These types of shifts were examined to illustrate the utility of using differences in spectral reflectance as an indicator of salt stress.

Percent reflectance was determined at one nm intervals between 400 and 800 nm wavelength with a Beckman UV-5240 Spectrophotometer equipped with an integrating sphere. Leaf material from two individuals of each species for the six salinity treatment groups was analyzed at 0, 30, 60, 90, and 120 days after commencement of salinization. Data collection in some salinity groups was precluded by various factors, such as the absence of adequate sacrificable leaf material in younger plants, and salt-induced or other types of mortality.

Our hypothesis was that salinity effects on plant growth could be interpreted by shifts in reflectance curves, particularly along the red edge of the spectrum. This shift is caused by decreased chlorophyll content, and subsequent decreased light absorption by leaves. The shift is subtle, so it was necessary to determine effects by graphical comparison of curves of the first derivative of spectral reflectance values between 680 and 750 nm.

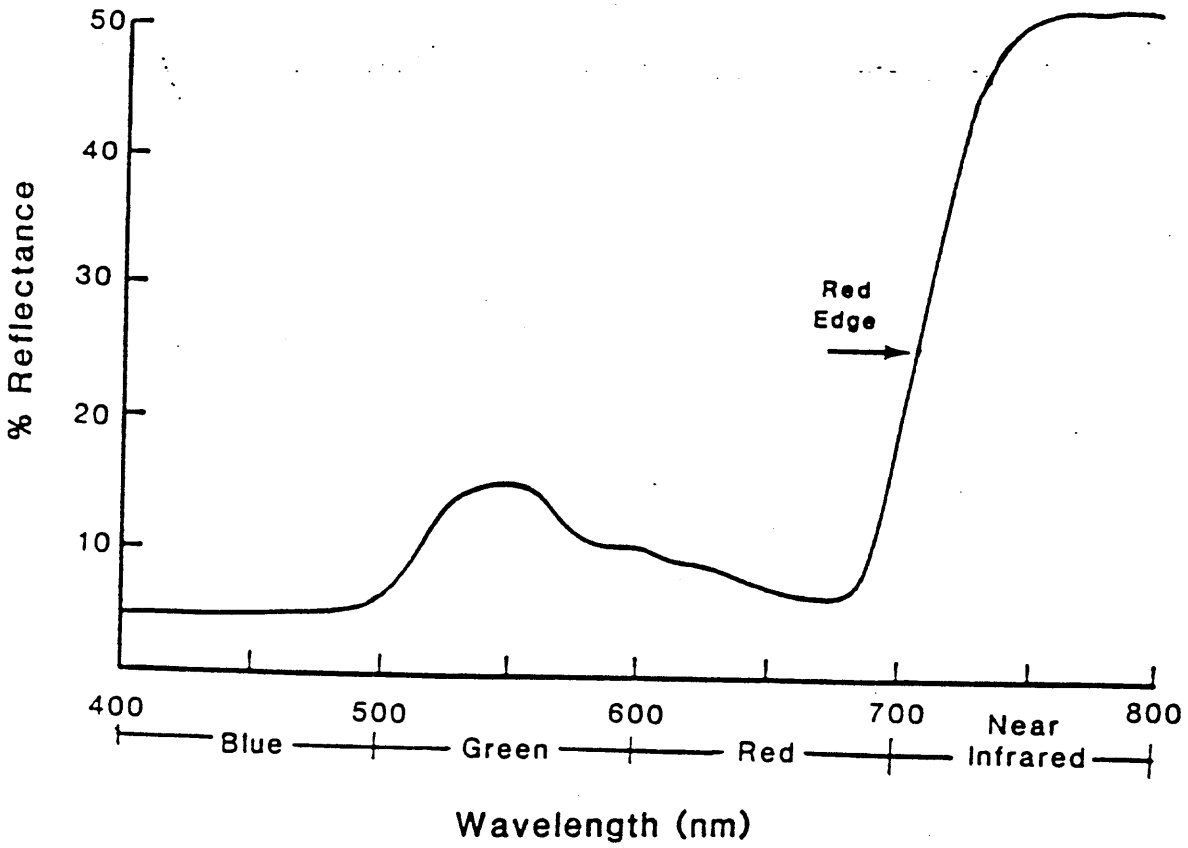


Figure 2
Spectral reflectance of green vegetation as a function of wavelength in the visible and near-infrared portions of the electromagnetic wavelength spectrum.

This procedure provided an in-depth examination of the difference between the instantaneous rate of change of the slope along the spectral red edge. Curves illustrating differences in the first derivative of spectral reflectance were prepared for data from each species collected at either Day-30 or Day-60, and compared to the results of the morphological data collection to determine whether the reflectance data were indicators of the precursors of morphological stress.

Photosynthesis

Measurements of photosynthesis were made on six individual plants of each species at each salinity level. These individuals were selected at random from the ten replicates of each species at each salinity. During the period that the salinity levels were being increased, measurements were made not more than two days prior to incrementing the salinity level. After final salinities were reached measurements were generally made at two

week intervals and not less then every thirty days. The actual measurement dates ranged from two days before to two days after the thirty-day intervals.

The measurements of photosynthetic carbon dioxide uptake, transpirational water loss, and leaf and air temperature were made with a Li-Cor model 6200 portable photosynthesis system. A description of the technical details involved in these measurements and of the system is available in the 6200 Technical Reference Manual which can be obtained from Li-Cor Inc., Box 4425, Lincoln, NE, 68504; (402-467-3576). A review of available methods for measuring photosynthesis and transpiration has recently been published in a volume on methods in physiological plant ecology (Field, Ball, and Berry, 1989), which reviews, in particular, advantages and disadvantages of the various measurement approaches.

Chlorophyll Fluorescence

Measurements of chlorophyll fluorescence were made on three individuals of each species at each final salinity level. The measurements were made using a pulse modulating fluorimeter which averages the emission over an area of a leaf (PAM Heinz Walz, Mess- und Regel technik, 8521 Effeltrich, FRG). High-intensity pulses of light were produced by an ILC-300 xenon arc lamp (ILC Corp. Menlo Park, CA) and their timing regulated by a high speed electronic shutter (Uniblitz, A.W. Vincent Assoc., Inc., Rochester, N.Y.)

The light pulses were filtered through 1 cm of water and a "blue" short-pass glass filter (Corning 9782). The flashes were guided to the leaf through the branched fiber-optic light guide provided with the PAM Fluorimeter. Flash quantum fluxes were 4000 micromole m^{-2} s^{-1} and limited to less than 2 seconds to avoid disturbing steady-state photosynthesis or damaging the leaf. The actinic light was supplied by a tungsten-halide lamp that was turned off during each flash.

Fluorescence images were obtained from the area of the leaf illuminated by the fiber-optic, PAM fluorimeter, xenon lamp combination. The images of an area approximately 6 mm in diameter were projected by a Canon FD 100-mm macro lens and Canon bellows combination fitted with a Schott RG 9 long pass filter (> 710 nm) onto the

charge-coupled device (CCD) in a COHU (model 4810) monochromatic camera. Images were captured by inputing the camera signals into a Data Translation (5300 series) video digitizer board mounted in an INTEL 80386-based personal computer.

Computation of the nonphotochemical fluorescence quenching coefficient was based on

$$q_{NP} = \frac{(F_M)_d - (F_M)_s}{(F_M)_d - F_o} \qquad \text{Eq. 1}$$

where $(F_M)_d$ is the maximum fluorescence signal during a saturating light pulse on a dark adapted (fully relaxed) leaf, $(F_M)_S$ is the flash saturated variable fluorescence yield during steady-state photosynthesis, and F_o is the fluorescence excited by the very weak beam of light emitted by the PAM fluorimeter as a probe. The parameter q_{NP} has been shown to be a measure of the state of what is essentially a "three-way valve" which regulates the flow of chemical energy to the photosynthetic process by regulating the diversion of energy from captured photons to energy dissipating "non-photochemical processes" within leaves. A value of q_{NP} close to 1 indicates that more of the energy is being non-productively dissipated then if the value of the parameter is close to zero (Krause et al. 1982, Bilger and Schreiber, 1986). This in essence gives a measure of the efficiency with which an incremental increase in light could be used by the plant. The value of q_{NP} can be calculated at high spatial resolution (pixel by pixel) from the digitized video images as was described by Daley et al. 1989.

Part 2: ANALYSIS OF SEED GERMINATION

The analysis of seed germination for the eight riparian species was conducted in a Precision 815 Low Temperature Incubator in DRI's Biogeochemistry Laboratory. One hundred seeds of each species in treatment groups of 25 seeds were germinated in covered petri dishes on blotter germination paper wetted with salinity solutions identical to those used during the analysis of seedling survival (Part 1). All seeds were incubated at 25°C over the four week experimental period. Trial experiments and references to the literature provided information on seed pre-treatments necessary to stimulate germination

(Table 4). All seeds were treated with Captan fungicide prior to testing. Seeds were examined for signs of germination every two days during the first week and then weekly thereafter up to 4 weeks. Germination was considered complete when the radicle had elongated and cotyledons had commenced development. Radicles of seeds which did not fully germinate were examined to determine the stage at which mortality occurred.

Table 4. Seed pre-treatments for eight riparian species tested for salt tolerance in the germination stage of growth

Species	Pre-Treatment
Atriplex lentiformis	Removal of utricles containing germination inhibitors
Allenrolfea occidentalis	None
Tessaria sericea	None
Tamarix chinensis	None
Prosopis juliflora torreyana	Scarification in 98% concentrated H_2SO_4 for 25 minutes
Prosopis pubescens	Scarification in 98% concentrated H_2SO_4 for 25 minutes
Populus fremontii	None
Salix gooddingii	None

RESULTS

Part 1: ANALYSIS OF SEEDLING GROWTH AND SURVIVAL

Survivorship

Atriplex and *Allenrolfea* demonstrated 100 percent survival across the experimental range of salinity (Table 5). *Tamarix* and both species of *Prosopis* achieved 100 percent survival up to 36,000 mg/l and limited mortality in the 60,000 mg/l groups. *Tessaria* exhibited high rates of mortality above 18,000 mg/l and *Populus* displayed 100 percent mortality beyond 1,500 mg/l. Nearly 100 percent mortality in *Salix* was exhibited at salinities beyond 1,500 mg/l.

Table 5. Percent survival of eight Sonoran Desert riparian species at 30, 60, 90, and 120 days

SPECIES	SALINITY (mg/l) 0	1,500	6,000	18,000	36,000	60,000
Atriplex lentiformis						
Day-30	100	100	100	90*	100	100
Day-60	100	100	100	90*	100	100
Day-90	100	100	100	90*	100	100
Day-120	100	100	100	90*	100	100
Allenrolfea occidentalis						
Day-30	100	100	100	100	90*	100
Day-60	90*	100	100	100	90*	100
Day-90	90*	100	100	100	90*	100
Day-120	90*	100	100	100	90*	100
Populus fremontii						
Day-30	100	100	100	100	100	100
Day-60	100	100	100	30	0	0
Day-90	100	100	70	0	0	0
Day-120	100	100	0	0	0	0
Prosopis juliflora var. *torreyana*						
Day-30	100	100	100	100	100	100
Day-60	100	100	100	100	100	100
Day-90	100	100	100	100	100	90
Day-120	100	100	100	100	100	90
Prosopis pubescens						
Day-30	100	100	100	100	100	100
Day-60	100	100	100	100	100	70
Day-90	100	100	100	100	100	70
Day-120	100	100	100	100	100	70

Table 5. Percent survival of eight Sonoran Desert riparian species at 30, 60, 90, and 120 days (cont.)

SPECIES	SALINITY (mg/l) 0	1,500	6,000	18,000	36,000	60,000
Salix gooddingii						
Day-30	100	100	100	100	100	90
Day-60	100	100	90	0	0	0
Day-90	100	100	20	0	0	0
Day-120	100	100	20	0	0	0
Tamarix chinensis						
Day-30	100	100	100	100	100	100
Day-60	100	100	100	100	100	70
Day-90	100	100	100	100	100	70
Day-120	100	100	100	100	100	70
Tessaris sericea						
Day-30	100	100	100	100	100	100
Day-60	100	100	100	100	50	0
Day-90	100	100	100	100	30	0
Day-120	100	100	100	100	30	0

* Mortality as a function of experimental error.

Morphological Growth Response

Pearson Correlation coefficients for correlations between seven growth variables and salinity are displayed in Table 6. Increasing salinity was correlated with decreased growth for all species except *Allenrolfea* and *Salix*. Shoot and root biomass were typically correlated with each other and with the stem length increases, which were more highly correlated over time. By exception, shoot biomass of *P. juliflora* was neither correlated with root biomass nor stem length. Root/shoot ratios were correlated with both root and shoot biomass (because this variable is composed of root and shoot biomass), but not with stem length increase.

Table 6. Pearson correlations between seven growth variables and salt concentration by species

Atriplex lentiformis

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	-0.431**	1.000			
SHOOT	-0.415**	0.708**	1.000		
R/S	0.036	0.125	-0.295*	1.000	
DAY-30	-0.254	0.606**	0.805**	-0.039	0.728**
DAY-60	-0.452**	0.649**	0.842**	-0.089	0.865**
DAY-90	-0.519**	0.633**	0.812**	-0.109	0.969**
DAY-120	-0.528**	0.666**	0.798**	-0.096	1.000

Allenrolfea occidentalis

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	0.086	1.000			
SHOOT	0.327*	0.774**	1.000		
R/S	-0.255	0.130	-0.211	1.000	
DAY-30	0.233	0.464**	0.497**	0.015	0.779**
DAY-60	0.183	0.626**	0.578**	-0.015	0.964**
DAY-90	0.130	0.648**	0.592**	-0.009	0.989**
DAY-120	0.172	0.570**	0.617**	-0.025	1.000

Populus fremontii

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	-0.581**	1.000			
SHOOT	-0.597**	0.891**	1.000		
R/S	-0.068	0.367**	0.115	1.000	
DAY-30	-0.690**	0.579**	0.590**	0.012	0.457*
DAY-60	-0.638**	0.520**	0.483**	0.273	0.934**
DAY-90	-0.709**	0.580**	0.558**	0.261	0.980**
DAY-120	-0.531*	0.528**	0.469*	0.296	1.000

Table 6. Pearson correlations between seven growth variables and salt concentration by species (cont.)

Prosopis juliflora var. *torreyana*

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	-0.321*	1.000			
SHOOT	-0.040	-0.108	1.000		
R/S	0.219	0.034	-0.391**	1.000	
DAY-30	-0.300*	0.437**	-0.018	-0.172	0.596**
DAY-60	-0.414**	0.645**	0.008	-0.258	0.872**
DAY-90	-0.393**	0.645**	0.010	-0.237	0.922**
DAY-120	-0.390**	0.588**	0.022	-0.187	1.000

Prosopis pubescens

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	-0.246	1.000			
SHOOT	-0.397**	0.797**	1.000		
R/S	0.033	0.256	-0.146	1.000	
DAY-30	-0.323*	0.421**	0.443**	0.055	0.513**
DAY-60	-0.424**	0.565**	0.612**	0.006	0.596**
DAY-90	-0.466**	0.566**	0.637**	-0.050	0.624**
DAY-120	-0.297*	0.298*	0.435**	-0.160	1.000

Salix gooddingii

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	-0.663**	1.000			
SHOOT	-0.660**	-0.947**	1.000		
R/S	0.137	0.110	-0.033	1.000	
DAY-30	-0.214	0.303	0.346	0.145	0.847**
DAY-60	-0.144	0.318	0.387*	0.168	0.900**
DAY-90	0.085	0.307	0.406	-0.039	0.947**
DAY-120	0.125	0.361	0.443	0.005	1.000

Table 6. Pearson correlations between seven growth variables and salt concentration by species (cont.)

Tamarix chinensis

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	-0.516**	1.000			
SHOOT	-0.587**	0.763**	1.000		
R/S	0.005	0.427**	-0.103	1.000	
DAY-30	-0.329**	0.407**	0.433**	0.107	0.505**
DAY-60	-0.486**	0.415**	0.463**	0.141	0.879**
DAY-90	0.544**	0.418**	0.503**	0.053	0.933**
DAY-120	-0.586**	0.387**	0.524**	-0.023	1.000

Tessaria sericea

	SALT	ROOT	SHOOT	R/S	DAY-120
ROOT	-0.385**	1.000			
SHOOT	-0.529**	0.430**	1.000		
R/S	-0.089	0.804**	-0.054	1.000	
DAY-30	-0.600**	0.585**	0.758**	0.199	0.787**
DAY-60	-0.627**	0.595**	0.730**	0.282	0.940**
DAY-90	0.643**	0.583**	0.650**	0.366*	0.988**
DAY-120	-0.659**	0.523**	0.654**	0.308	1.000

* $P \leq .05$

** $P \leq .01$

Tables 7 through 14 and Figures 3 through 10 provide the results of the statistical analyses by species and by growth variable. Although overall growth responses for each of the eight species followed similar patterns, growth response variations were detectable within each species group. Shoot and root biomass variables frequently indicated positive growth responses to salinity, however there were few significant differences in growth apparent from the on root/shoot ratios. Stem length increases over time (Day-30, Day-60, Day-90, and Day-120) were useful indicators of growth response to salinity. The results of the leaf area analyses generally did not provide conclusive information about plant response.

Atriplex lentiformis. Growth responses by *Atriplex* seedlings grown under six salinity concentrations suggest that this species is able to grow under a range of salinity. The Shoot, Root, Day-60, Day-90 and Day-120 growth response variables each indicated comparable growth responses among the 0, 1,500, 6,000, and 18,000 mg/l groups. Growth responses were notably decreased in the 36,000 and 60,000 mg/l groups (Figure 3a, b, e, f, and g).

Results of the ANOVAs indicated that the growth response variables (except R/S ratio and Day-30) were significantly different across salinity treatments (Table 7). Shoot biomass was significantly greater in the 6,000 and 18,000,mg/l groups than in the 36,000 or 60,000 mg/l groups. Total stem growth increases in the 0, 1,500, 6,000, and 18,000 mg/l groups were significantly greater than increases in the 36,000 and 60,000 mg/l groups (Table 7). These differences became even greater over time. Standard deviations of the mean for leaf areas of *Atriplex* overlapped across all salinity levels, indicating no significant differences in leaf area across the range of salinity.

Allenrolfea occidentalis. *Allenrolfea* shoot biomass varied both among and within groups and did not provide a clear indicator of the species response to salinity (Figure 4b). Root biomass response and stem growth increases at Days-60, -90, and -120 appeared slightly greater among the 6,000, 18,000, and 36,000 mg/l groups than among the 0, 1,500 or 60,000 mg/l groups (Figure 4a, e, f, and g).

Few significant differences in growth response among the salinity groups were detected with the ANOVA. Comparisons between cumulative stem length increases at Days-60, -90, and -120 (Table 8) indicated an overall difference in growth response between groups. However, multiple comparison tests to discern differences among treatments were not statistically significant. Slow rates of growth among *Allenrolfea* seedlings grown for this study may have precluded definitive growth response to salinity treatments. The aboveground portions of *Allenrolfea* were comprised of photosynthetic stems rather than leaves, thus leaf area measurement was not applicable.

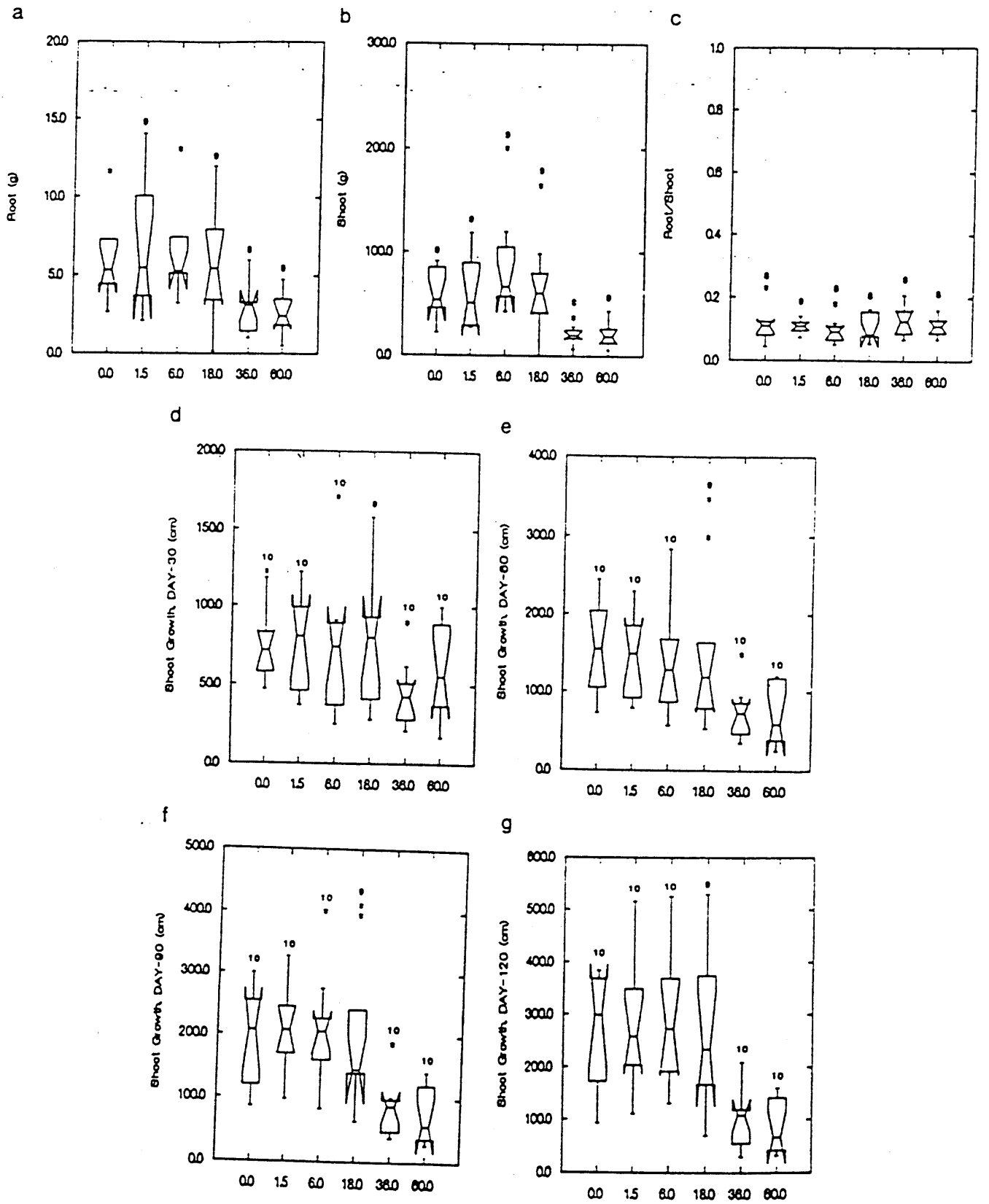


Figure 3

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Atriplex lentiformis*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 7. Results of the ANOVA and multiple comparisons tests by growth variable for *Atriplex lentiformis*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

7a

Variable = Root
ANOVA $F_{5,48} = 3.252$; $p = .013$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	7.08	0.00					
1,500	7.04	0.04	0.00				
6,000	7.97	-0.89	-0.93	0.00			
18,000	5.97	1.10	1.07	2.00	0.00		
36,000	2.69	4.34	4.35	5.28	3.28	0.00	
60,000	2.49	4.58	4.54	5.47	3.47	0.19	0.00

7b

Variable = Shoot
ANOVA $F_{5,48} = 5.757$; $p < 0.0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	58.83	0.00					
1,500	62.61	-3.78	0.00				
6,000	85.96	-27.13	-23.35	0.00			
18,000	67.26	-8.43	-4.65	18.70	0.00		
36,000	20.99	37.84	41.62	64.97**	46.27*	0.00	
60,000	20.56	38.27	42.05	65.40**	46.70*	0.43	0.00

7c

Variable = R/S
ANOVA $F_{5,48} = 0.488$; $p = 0.783$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.14
1,500	0.11
6,000	0.09
18,000	0.15
36,000	0.13
60,000	0.13

Table 7. Results of the ANOVA and multiple comparisons tests by growth variable for *Atriplex lentiformis* (cont.)

7d

Variable = Day-30
ANOVA $F_{5,53} = 1.712$; $p = 0.148$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Day-30 (cm)
0	75.7
1,500	76.0
6,000	72.0
18,000	81.8
36,000	44.0
60,000	57.2

7e

Variable = Day-60
ANOVA $F_{5,53} = 4.284$; $p = .002$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	155.6	0.0					
1,500	143.7	11.9	0.0				
6,000	137.3	18.3	6.4	0.0			
18,000	154.9	0.7	-11.2	-17.6	0.0		
36,000	71.8	83.8*	71.9	65.5	83.1	0.0	
60,000	68.4	87.2*	75.3	68.9	86.5*	3.4	0.0

7f

Variable = Day-90
ANOVA $F_{5,53} = 6.745$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	195.8	0.0					
1,500	210.8	-15.0	0.0				
6,000	208.8	-13.0	2.0	0.0			
18,000	199.3	-3.5	11.5	9.5	0.0		
36,000	84.8	111.0*	126.0**	124.0*	114.5*	0.0	
60,000	72.6	123.2*	138.2**	136.2**	126.7*	12.2	0.0

Table 7. Results of the ANOVA and multiple comparisons tests by growth variable for *Atriplex lentiformis* (cont.)

7g

Variable = Day-120
ANOVA $F_{5,53} = 8.064$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	262.1	0.0					
1,500	291.6	-29.5	0.0				
6,000	305.4	-43.3	-13.8	0.0			
18,000	276.9	-14.8	14.7	28.5	0.0		
36,000	103.1	159.0*	188.5**	202.3**	173.8*	0.0	
60,000	84.1	178.0**	207.5**	221.3**	192.8**	19.0	0.0

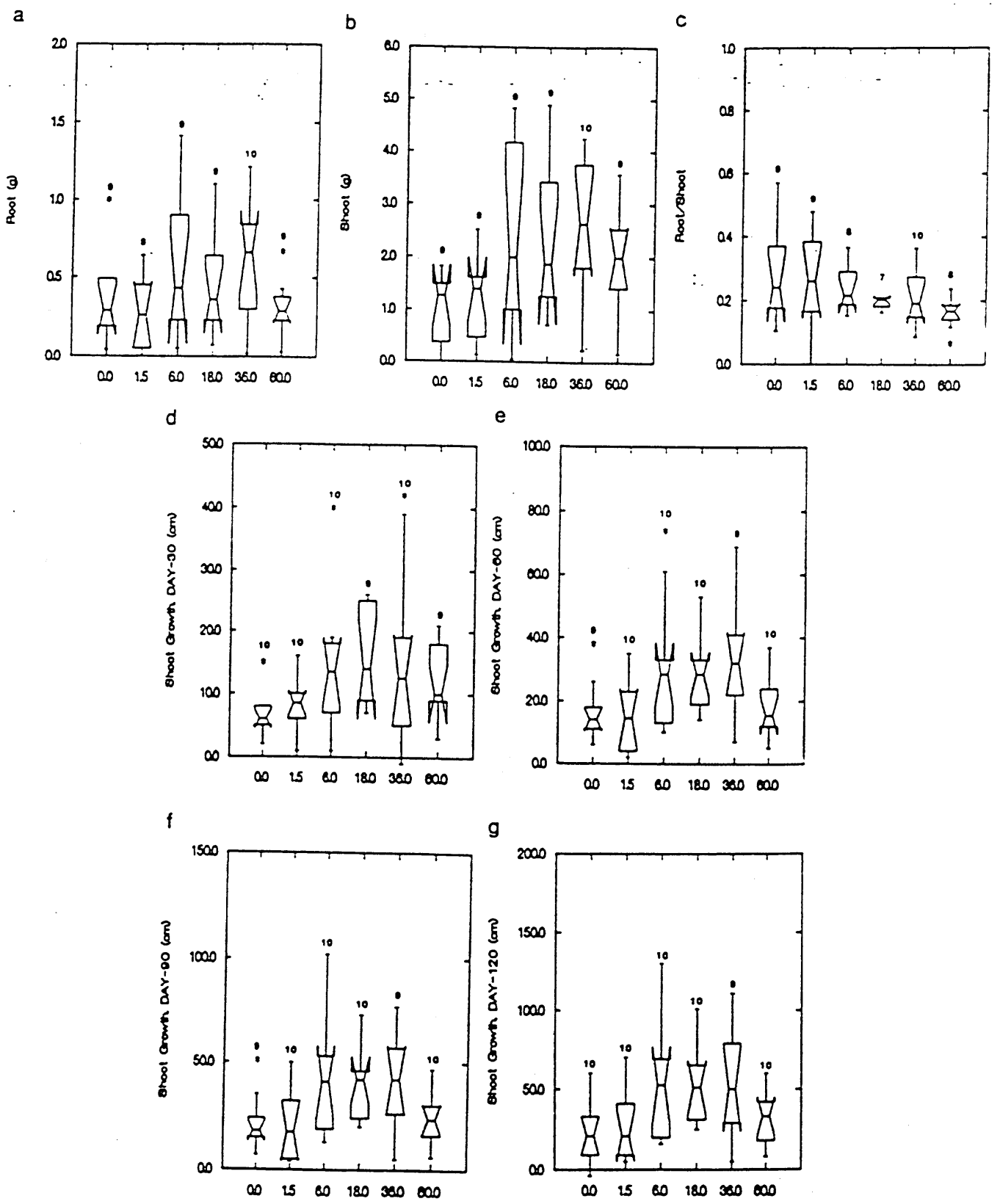


Figure 4

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Allenrolfea occidentalis*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 8. Results of the ANOVA and multiple comparisons tests by growth variable for *Allenrolfea occidentalis*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

8a

Variable = Root
ANOVA: $F_{5,49} = 1.374$; $p = .250$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)
0	0.35
1,500	0.29
6,000	0.57
18,000	0.47
36,000	0.59
60,000	0.31

8b

Variable = Shoot
ANOVA: $F_{5,49} = 2.392$; $p = .051$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)
0	1.01
1,500	1.21
6,000	2.33
18,000	2.26
36,000	2.54
60,000	1.96

8c

Variable = R/S
ANOVA: $F_{5,48} = 1.127$; $p = .359$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.28
1,500	0.26
6,000	0.32
18,000	0.21
36,000	0.21
60,000	0.18

8d

Variable = Day-30
ANOVA: $F_{5,54} = 1.566$; $p = .185$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)
0	8.2
1,500	8.4
6,000	14.8
18,000	15.8
36,000	15.8
60,000	12.2

Table 8. Results of the ANOVA and multiple comparisons tests by growth variable for *Allenrolfea occidentalis* (cont.)

8e

Variable = Day-60
ANOVA: $F_{5,52} = 2.813$; $p = .025$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	16.2	0.0					
1,500	14.8	1.4	0.0				
6,000	30.4	-14.2	-15.6	0.0			
18,000	28.7	-12.5	-13.9	1.7	0.0		
36,000	33.4	-17.2	-18.6	-3.0	-4.7	0.0	
60,000	18.2	-2.0	-3.4	12.2	10.5	15.2	0.0

8f

Variable = Day-90
ANOVA: $F_{5,52} = 2.522$; $p = .041$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	21.9	0.0					
1,500	21.4	0.5	0.0				
6,000	44.5	-22.6	-23.1	0.0			
18,000	39.6	-17.7	-18.2	4.9	0.0		
36,000	40.3	-18.4	-18.9	4.2	-0.7	0.0	
60,000	24.2	-2.3	-2.8	20.3	15.4	16.1	0.0

8g

Variable = Day-120
ANOVA: $F_{5,53} = 2.706$; $p = .030$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	23.9	0.0					
1,500	28.3	-4.4	0.0				
6,000	57.3	-33.4	-29.0	0.0			
18,000	53.9	-30.0	-25.6	3.4	0.0		
36,000	52.4	-28.5	-24.1	4.9	1.5	0.0	
60,000	31.7	-7.8	-3.4	25.6	22.2	20.7	0.0

Populus fremontii. The effects of nearly 100 percent mortality among the 36,000 and 60,000 mg/l salinity groups soon after Day-30, and in the 18,000 mg/l group after Day-60 are apparent through examination of root and shoot biomass responses (Figure 5a and b). Reductions in stem length increases over time were also indicative of high mortality throughout the experiment (Figure 5d, e, f, and g). By Day-120, survival was limited to the 0 and 1,500 mg/l groups.

ANOVA and multiple comparison tests of differences in stem and root biomass among the groups revealed significantly greater growth response among the 0 and 1,500 mg/l groups compared to all other groups (Table 9). Day-30 stem lengths were significantly greater at 0 and 1,500 mg/l than at 18,000, 36,000, or 60,000 mg/l. Stem growth at 6,000 mg/l gradually declined over time and 100 percent mortality was achieved prior to Day-120. Differences in growth responses on Day-120 among the 0 and 1,500 mg/l groups were not significant (T statistic= 1.633). Differences in mean leaf surface area of the surviving *Populus* were not discernable between 0 and 1,500 mg/l.

Prosopis juliflora* var. *torreyana. Overall growth responses of *P. juliflora* to salinity based on analysis of shoot, root, Day-30, and Day-90 variables were unclear (Figure 6). Shoot length increases varied slightly at Days-60 and -120, suggesting reduced growth responses at higher salinity levels. ANOVA tests indicated significant differences in growth at Day-60 and Day-120, and multiple comparison testing revealed differences in growth between the 0 and 18,000 mg/l groups on Day-120 (Table 10). Standard deviations of the mean leaf areas of *P. juliflora* overlapped across all salinity levels, indicating no significant differences in leaf area across the range of salinity.

Prosopis pubescens. Growth responses in *P. pubescens* varied to a limited extent with increasing salinity. Shoot and root biomass appeared fairly constant across all salinity treatments (Figure 7a and b), however, a trend towards reduced stem growth was evident with increasing salinity, particularly within the 36,000 and 60,000 mg/l groups (Figure 7d, e, f, and g).

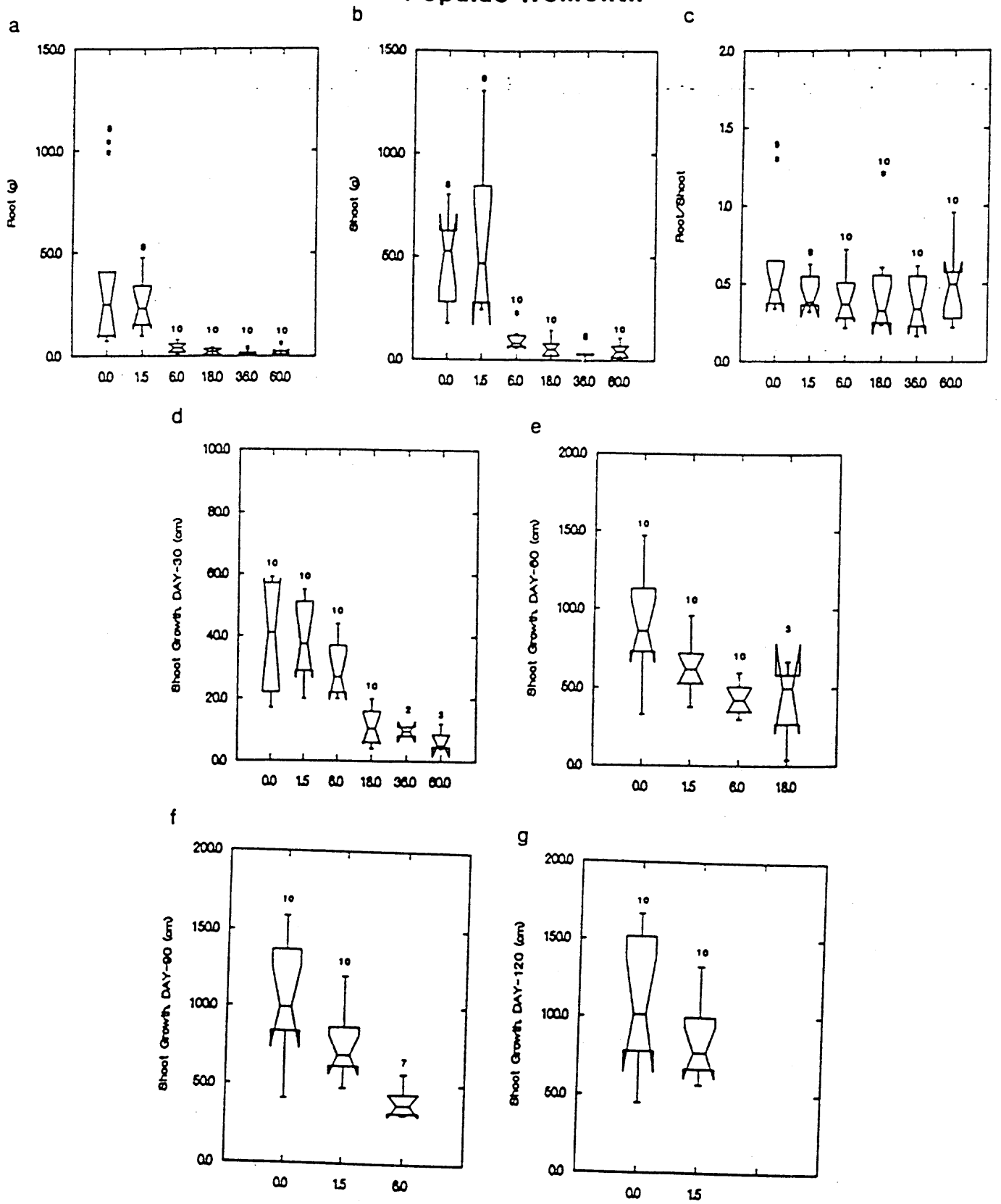


Figure 5

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Populus fremontii*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 9. Results of the ANOVA and multiple comparisons tests by growth variable for *Populus fremontii*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

9a

Variable = Root
ANOVA: $F_{5,52} = 8.890$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	38.21	0.00					
1,500	25.82	12.39	0.00				
6,000	4.09	34.12**	21.73	0.00			
18,000	2.03	36.19**	23.79*	2.06	0.00		
36,000	1.41	36.80**	24.41*	2.68	0.61	0.00	
60,000	2.19	36.02**	23.63*	1.90	-0.16	-0.78	0.00

9b

Variable = Shoot
ANOVA: $F_{5,52} = 9.811$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	62.77	0.00					
1,500	60.29	2.48	0.00				
6,000	10.03	52.74**	50.26**	0.00			
18,000	5.73	57.05**	54.57**	4.31	0.00		
36,000	3.42	59.35**	56.87**	6.61	2.31	0.00	
60,000	4.75	58.02**	55.54**	5.28	0.98	-1.33	0.00

9c

Variable = R/S
ANOVA: $F_{5,52} = 0.793$; $p = .560$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.56
1,500	0.45
6,000	0.40
18,000	0.45
36,000	0.39
60,000	0.52

Table 9. Results of the ANOVA and multiple comparisons tests by growth variable for *Populus fremontii* (cont.)

9d

Variable = Day-30
ANOVA: $F_{5,39} = 8.527$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	39.4	0.0					
1,500	38.5	1.2	0.0				
6,000	29.0	8.1	6.9	0.0			
18,000	14.2	16.9**	15.7*	8.8	0.0		
36,000	9.5	23.4**	22.2**	15.3*	6.5	0.0	
60,000	7.0	21.4**	20.2**	13.3	4.5	2.0	0.0

9e

Variable = Day-60
ANOVA: $F_{3,29} = 7.455$; $p = .001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000		
		Pairwise Mean Differences (cm)					
0	88.0	0.0					
1,500	63.6	24.4	0.0				
6,000	42.8	45.2*	20.8	0.0			
18,000	40.3	47.7*	23.3	2.5	0.0		

9f

Variable = Day-90
ANOVA: $F_{2,24} = 12.684$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)	Salinity (mg/l)					
		0	1,500	6,000			
		Pairwise Mean Differences (cm)					
0	102.0	0.0					
1,500	75.5	26.5	0.0				
6,000	32.9	69.1**	42.6**	0.0			

Table 9. Results of the ANOVA and multiple comparisons tests by growth variable for *Populus fremontii* (cont.)

9g

Variable = Day-120
T-Statistic = 1.633; p = .120

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)
0	107.5
1,500	84.0

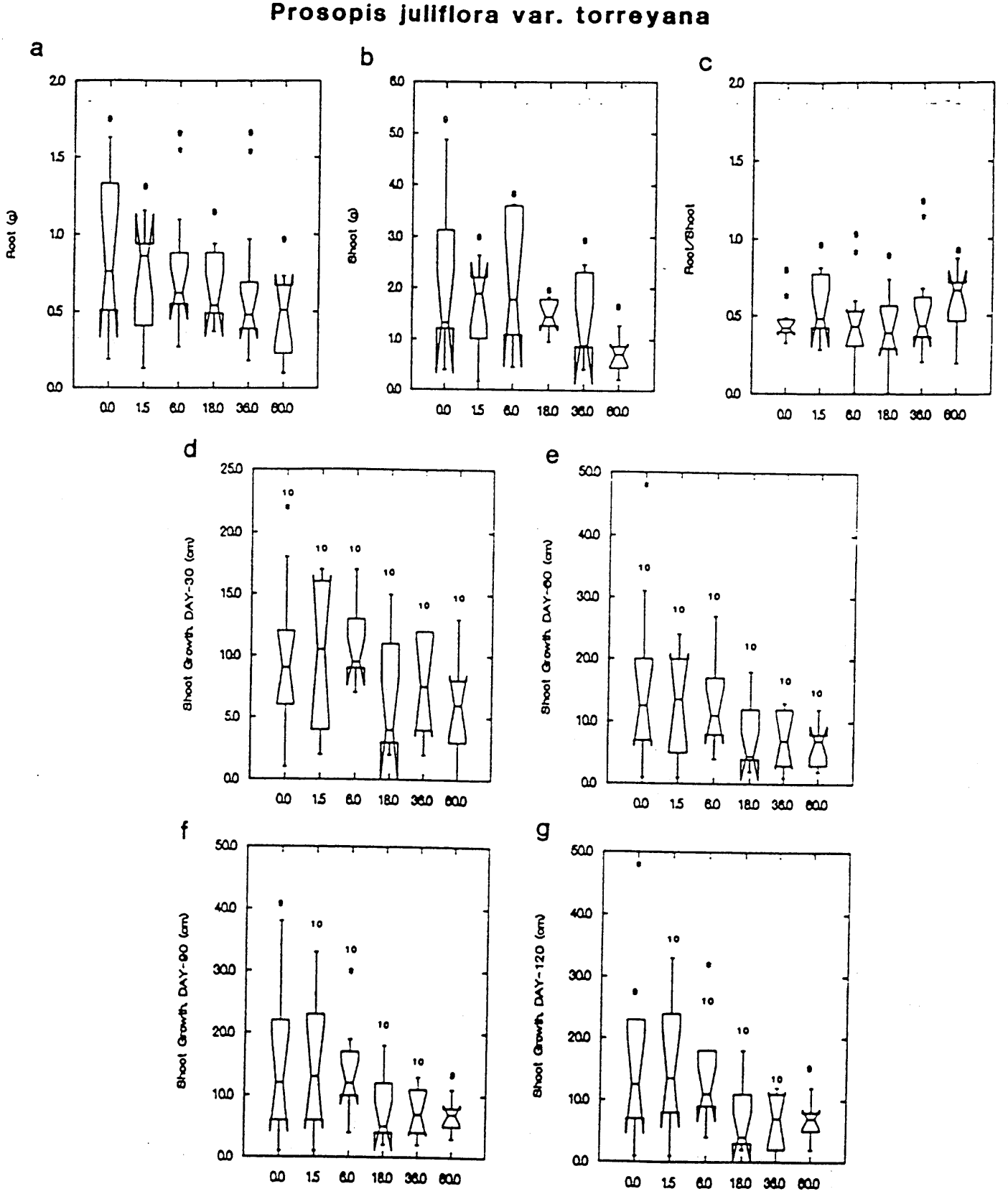


Figure 6

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Prosopis juliflora* var. *torreyana*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 10. Results of the ANOVA and pairwise multiple comparisons tests by growth variable for *Prosopis juliflora* var. *torreyana*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

10a

Variable = Root
ANOVA: $F_{5,48} = 1.219$; $p = .315$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)
0	0.86
1,500	0.72
6,000	0.72
18,000	0.62
36,000	0.62
60,000	0.45

10b

Variable = Shoot
ANOVA: $F_{5,48} = 0.872$; $p = .507$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)
0	2.07
1,500	1.16
6,000	8.97
18,000	7.26
36,000	1.40
60,000	0.69

10c

Variable = R/S
ANOVA: $F_{5,48} = 1.376$; $p = .250$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.44
1,500	0.54
6,000	0.44
18,000	0.42
36,000	0.52
60,000	0.71

10d

Variable = Day-30
ANOVA: $F_{5,54} = 2.080$; $p = .082$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)
0	9.9
1,500	10.0
6,000	12.0
18,000	6.6
36,000	7.7
60,000	5.7

Table 10. Results of the ANOVA and pairwise multiple comparisons tests by growth variable for *Prosopis juliflora* var. *torreyana* (cont.)

10e

Variable = Day-60
ANOVA: $F_{5,54} = 2.493$; $p = .042$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	16.2	0.0					
1,500	12.8	3.4	0.0				
6,000	12.7	3.5	0.1	0.0			
18,000	7.7	8.5	5.1	5.0	0.0		
36,000	7.3	8.9	5.5	5.4	0.4	0.0	
60,000	6.5	9.7	6.3	6.2	1.2	0.8	0.0

10f

Variable = Day-90
ANOVA: $F_{5,53} = 2.187$; $p = .069$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)
0	19.6
1,500	14.6
6,000	13.6
18,000	7.7
36,000	7.5
60,000	6.8

10g

Variable = Day-120
ANOVA: $F_{5,53} = 2.621$; $p = .034$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	23.2	0.0					
1,500	15.2	8.0	0.0				
6,000	13.4	9.8	1.8	0.0			
18,000	3.5	19.7*	11.7	9.9	0.0		
36,000	5.7	17.5	9.5	7.7	-2.2	0.0	
60,000	6.7	16.5	8.5	6.7	-3.2	-1.0	0.0

Table 10. Results of the ANOVA and pairwise multiple-comparisons tests by growth variable for *Prosopis juliflora* var. *torreyana*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

10a

Variable = Root
ANOVA: $F_{5,48} = 1.219$; $p = .315$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)
0	0.86
1,500	0.72
6,000	0.72
18,000	0.62
36,000	0.62
60,000	0.45

10b

Variable = Shoot
ANOVA: $F_{5,48} = 0.872$; $p = .507$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)
0	2.07
1,500	1.16
6,000	8.97
18,000	7.26
36,000	1.40
60,000	0.69

10c

Variable = R/S
ANOVA: $F_{5,48} = 1.376$; $p = .250$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.44
1,500	0.54
6,000	0.44
18,000	0.42
36,000	0.52
60,000	0.71

10d

Variable = Day-30
ANOVA: $F_{5,54} = 2.080$; $p = .082$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)
0	9.9
1,500	10.0
6,000	12.0
18,000	6.6
36,000	7.7
60,000	5.7

Table 10. Results of the ANOVA and pairwise multiple comparisons tests by growth variable for *Prosopis juliflora* var. *torreyana* (cont.)

10e

Variable = Day-60
ANOVA: $F_{5,54} = 2.493$; $p = .042$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	16.2	0.0					
1,500	12.8	3.4	0.0				
6,000	12.7	3.5	0.1	0.0			
18,000	7.7	8.5	5.1	5.0	0.0		
36,000	7.3	8.9	5.5	5.4	0.4	0.0	
60,000	6.5	9.7	6.3	6.2	1.2	0.8	0.0

10f

Variable = Day-90
ANOVA: $F_{5,53} = 2.187$; $p = .069$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)
0	19.6
1,500	14.6
6,000	13.6
18,000	7.7
36,000	7.5
60,000	6.8

10g

Variable = Day-120
ANOVA: $F_{5,53} = 2.621$; $p = .034$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	23.2	0.0					
1,500	15.2	8.0	0.0				
6,000	13.4	9.8	1.8	0.0			
18,000	3.5	19.7*	11.7	9.9	0.0		
36,000	5.7	17.5	9.5	7.7	-2.2	0.0	
60,000	6.7	16.5	8.5	6.7	-3.2	-1.0	0.0

Statistical analysis revealed that growth responses based on shoot, root, Day-60, Day-90, and Day-120 variables were significantly different (Table 11). Multiple comparison tests indicated differences in shoot biomass for plants grown at 0 mg/l and 60,000 mg/l. Differences in stem length increases in the 0 mg/l and 36,000 mg/l groups were also detected at Day-60 and Day-90. Standard deviations of the mean leaf areas of *P. pubescens* overlapped across all salinity levels, indicating no significant differences in leaf area across the range of salinity.

Salix gooddingii. Shoot and root biomass responses indicate that *Salix* is intolerant of salinity greater than 1,500 mg/l (Figure 8a and b). Growth responses in shoot and root biomass at 0 and 1,500 mg/l were significantly greater than responses at higher salinities (Table 12). Growth was reduced at salt concentrations of 18,000 mg/l and above during the first 30 days of the experiment (Figure 8d). Beyond Day-60, shoot length responses in the 0 mg/l and 6,000 mg/l groups were similar (Figure 8f and g), however, 80 percent mortality occurred in the 6,000 mg/l group during this time. The 1,500 mg/l group exhibited slightly greater shoot growth response than the 0 mg/l group at Day-60, Day-90, and Day-120 (Figure 8e, f, and g), however these differences were not statistically significant (Table 12). Differences in mean leaf surface area of the surviving *Salix* were not discernable between 0 and 1,500 mg/l.

Tamarix chinensis. Growth responses by *Tamarix* seedlings generally indicate growth reductions at higher salinity levels. Differences in shoot and root biomass are apparent beyond 18,000 mg/l (Figure 9a and b). There is substantial variation in root biomass below this salinity level. Stem length increases generally declined over time and with increasing salinity (Figure 9d, e, f, and g).

Analysis of variables for shoot and root biomass, and shoot length increases at Days 60, 90, and 120 indicate some significant differences in *Tamarix* seedling growth at 0 or 1,500 mg/l and salinity levels of 36,000 mg/l and 60,000 mg/l (Table 13). Shoot biomass at 6,000 mg/l was also greater than at either 36,000 or 60,000 mg/l, and Day-120 growth

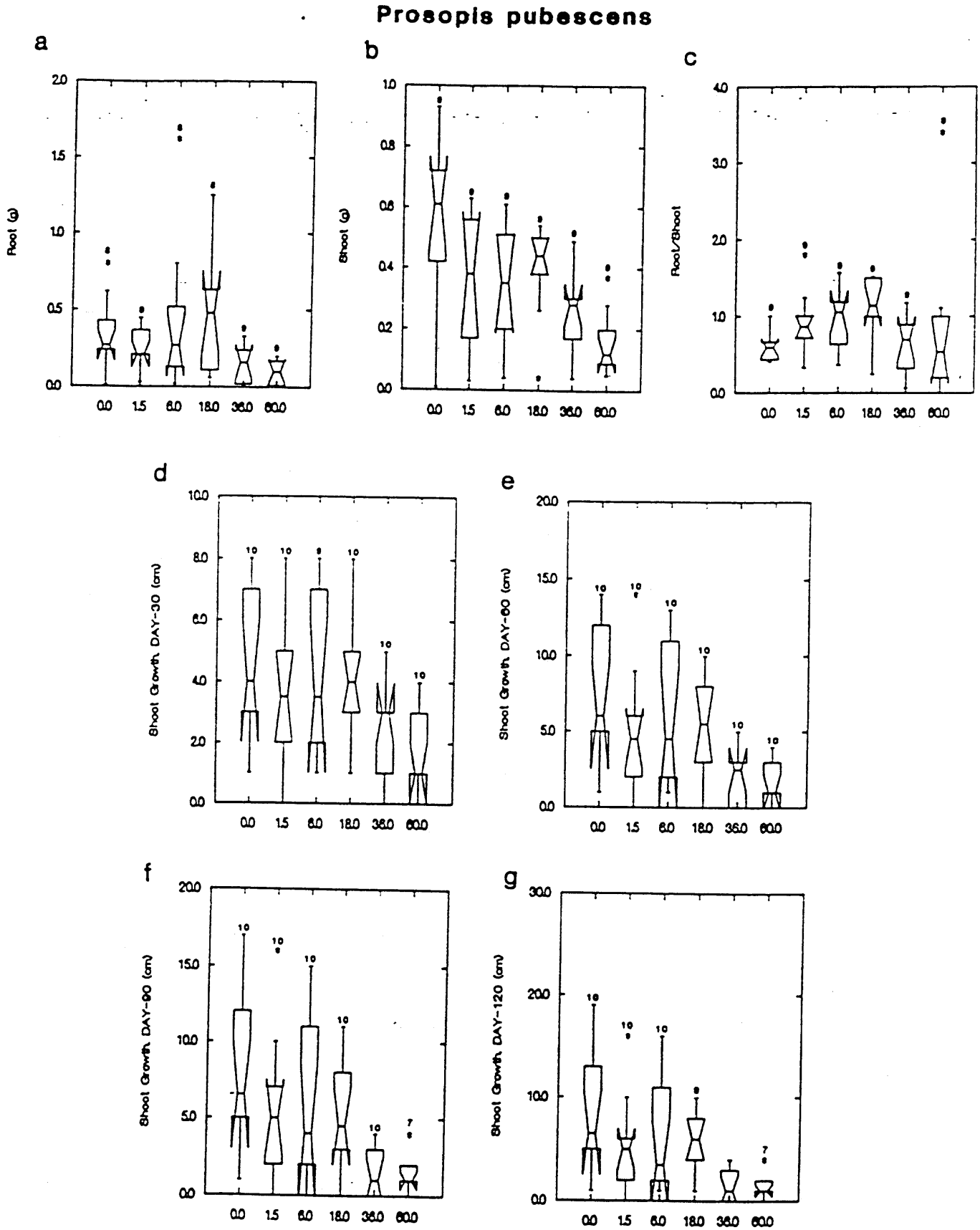


Figure 7

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Prosopis pubescens*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 11. Results of the ANOVA and multiple comparisons tests by growth variable for *Prosopis pubescens*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

11a

Variable = Root
ANOVA: $F_{5,48} = 2.618$; $p = .036$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	0.36	0.00					
1,500	0.25	0.11	0.00				
6,000	0.45	-0.09	-0.20	0.00			
18,000	0.48	-0.12	-0.23	-0.03	0.00		
36,000	0.15	0.20	0.10	0.29	0.32	0.00	
60,000	0.10	0.26	0.15	0.35	0.38	0.06	0.00

11b

Variable = Shoot
ANOVA: $F_{5,48} = 2.758$; $p = .029$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	0.66	0.00					
1,500	0.34	0.32	0.00				
6,000	0.44	0.23	-0.09	0.00			
18,000	0.45	0.21	-0.11	-0.02	0.00		
36,000	0.27	0.39	0.07	0.16	0.18	0.00	
60,000	0.16	0.50*	0.19	0.28	0.29	0.11	0.00

11c

Variable = R/S
ANOVA: $F_{5,48} = 1.029$; $p = .411$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.60
1,500	0.92
6,000	0.98
18,000	1.06
36,000	0.63
60,000	0.83

Table 11. Results of the ANOVA and multiple comparisons tests by growth variable for *Prosopis pubescens* (cont.)

11d

Variable = Day-30
ANOVA: $F_{5,54} = 2.221$; $p = .065$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)
0	4.6
1,500	3.5
6,000	3.9
18,000	4.2
36,000	0.6
60,000	1.6

11e

Variable = Day-60
ANOVA: $F_{5,51} = 3.507$; $p = .008$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	7.3	0.0					
1,500	5.1	2.2	0.0				
6,000	6.0	1.3	-0.9	0.0			
18,000	5.3	2.0	-0.2	0.7	0.0		
36,000	0.2	7.1**	4.9	5.8	5.1	0.0	
60,000	1.9	5.4	3.2	4.1	3.4	-1.7	0.0

11f

Variable = Day-90
ANOVA: $F_{5,51} = 4.031$; $p = .004$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	8.0	0.0					
1,500	5.5	2.5	0.0				
6,000	5.8	2.2	-0.3	0.0			
18,000	5.2	2.8	0.3	0.6	0.0		
36,000	0.2	8.2**	5.7	6.0	5.4	0.0	
60,000	1.6	6.4	3.9	4.2	3.6	-1.8	0.0

Table 11. Results of the ANOVA and multiple comparisons tests by growth variable for *Prosopis pubescens* (cont.)

11g

Variable = Day-120
ANOVA: $F_{5,51} = 2.537$; $p = .040$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	8.3	0.0					
1,500	5.5	2.8	0.0				
6,000	5.9	2.4	0.4	0.0			
18,000	9.2	-0.9	3.7	-3.3	0.0		
36,000	0.9	7.4	-4.6	5.0	8.3	0.0	
60,000	1.6	6.7	3.9	4.3	7.6	-0.7	0.0

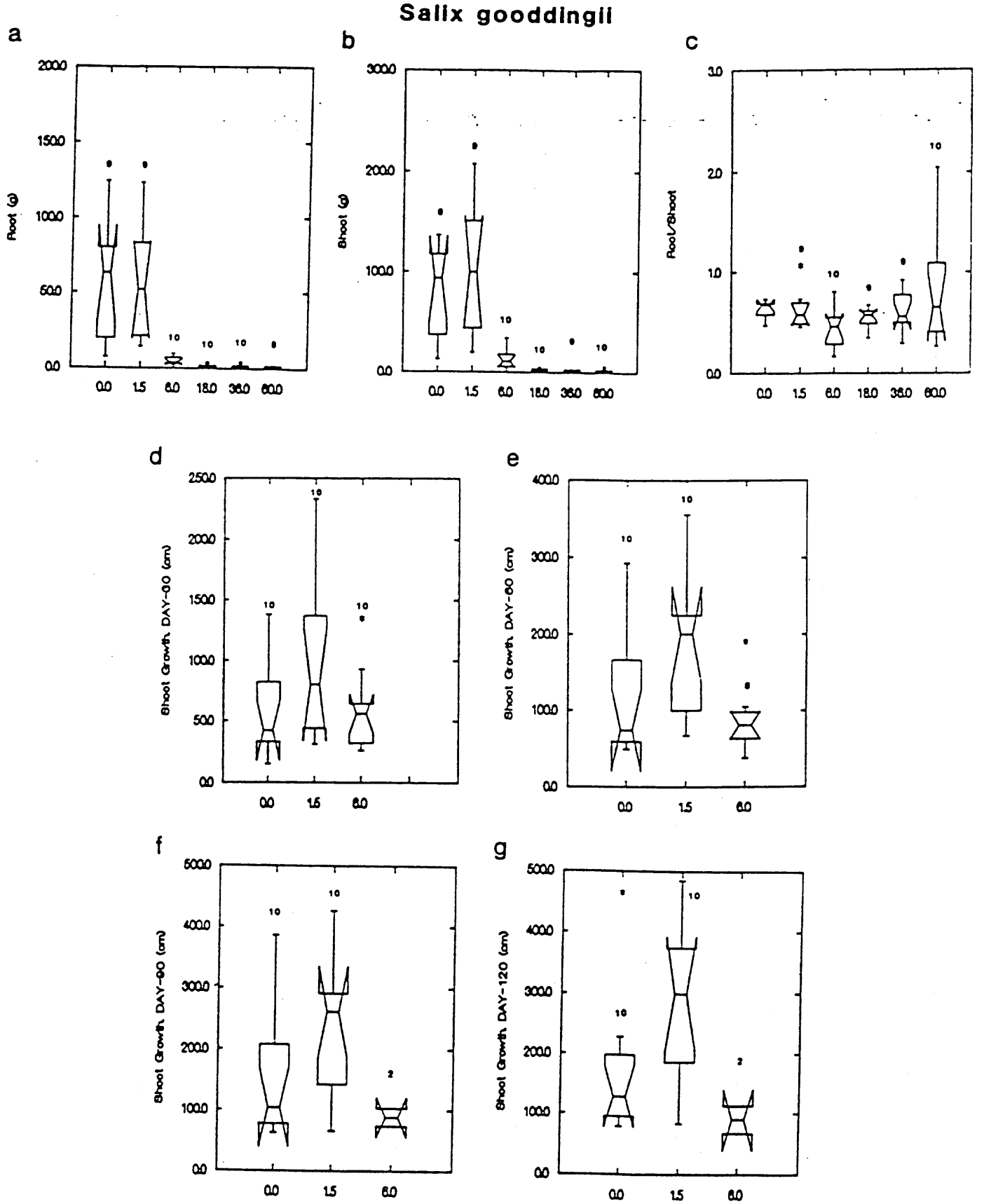


Figure 8

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Salix gooddingii*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 12. Results of the ANOVA and multiple comparisons tests by growth variable for *Salix gooddingii*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = P ≤ .05; ** = P ≤ .01)

12a

Variable = Root
ANOVA: $F_{5,52} = 16.745$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	58.05	0.00					
1,500	55.89	2.16	0.00				
6,000	5.03	53.02**	50.86**	0.00			
18,000	1.70	56.35**	54.19**	3.33	0.00		
36,000	1.55	56.49**	54.33**	3.47	0.15	0.00	
60,000	1.46	56.59**	54.43**	3.57	0.24	0.10	0.00

12b

Variable = Shoot
ANOVA: $F_{5,52} = 17.174$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	79.81	0.00					
1,500	96.47	16.67	0.00				
6,000	13.60	66.21**	82.88**	0.00			
18,000	3.07	76.74**	93.41**	10.53	0.00		
36,000	2.70	77.11**	93.77**	10.90	0.37	0.00	
60,000	2.07	77.74**	94.40**	11.53	1.00	0.63	0.00

12c

Variable = R/S
ANOVA: $F_{5,52} = 1.510$; $p = .203$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.70
1,500	0.63
6,000	0.45
18,000	0.59
36,000	0.67
60,000	0.82

Table 12. Results of the ANOVA and multiple comparisons tests by growth variable for *Salix gooddingii* (cont.)

12d

Variable = Day-30
ANOVA: $F_{2,27} = 2.129$; $p < .139$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)
0	56.5
1,500	97.1
6,000	56.9

12e

Variable = Day-60
ANOVA: $F_{2,26} = 3.638$; $p = .040$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000			
		Pairwise Mean Differences (cm)					
0	120.7	0.0					
1,500	183.5	62.8	0.0				
6,000	87.6	33.1	95.9*	0.0			

12f

Variable = Day-90
ANOVA: $F_{2,19} = 2.578$; $p = .102$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)
0	153.2
1,500	238.6
6,000	88.0

12g

Variable = Day-120
ANOVA: $F_{2,19} = 3.765$; $p = .042$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)					
		0	1,500	6,000			
		Pairwise Mean Differences (cm)					
0	165.1	0.0					
1,500	284.5	119.4	0.0				
6,000	90.0	75.1	194.5**	0.0			

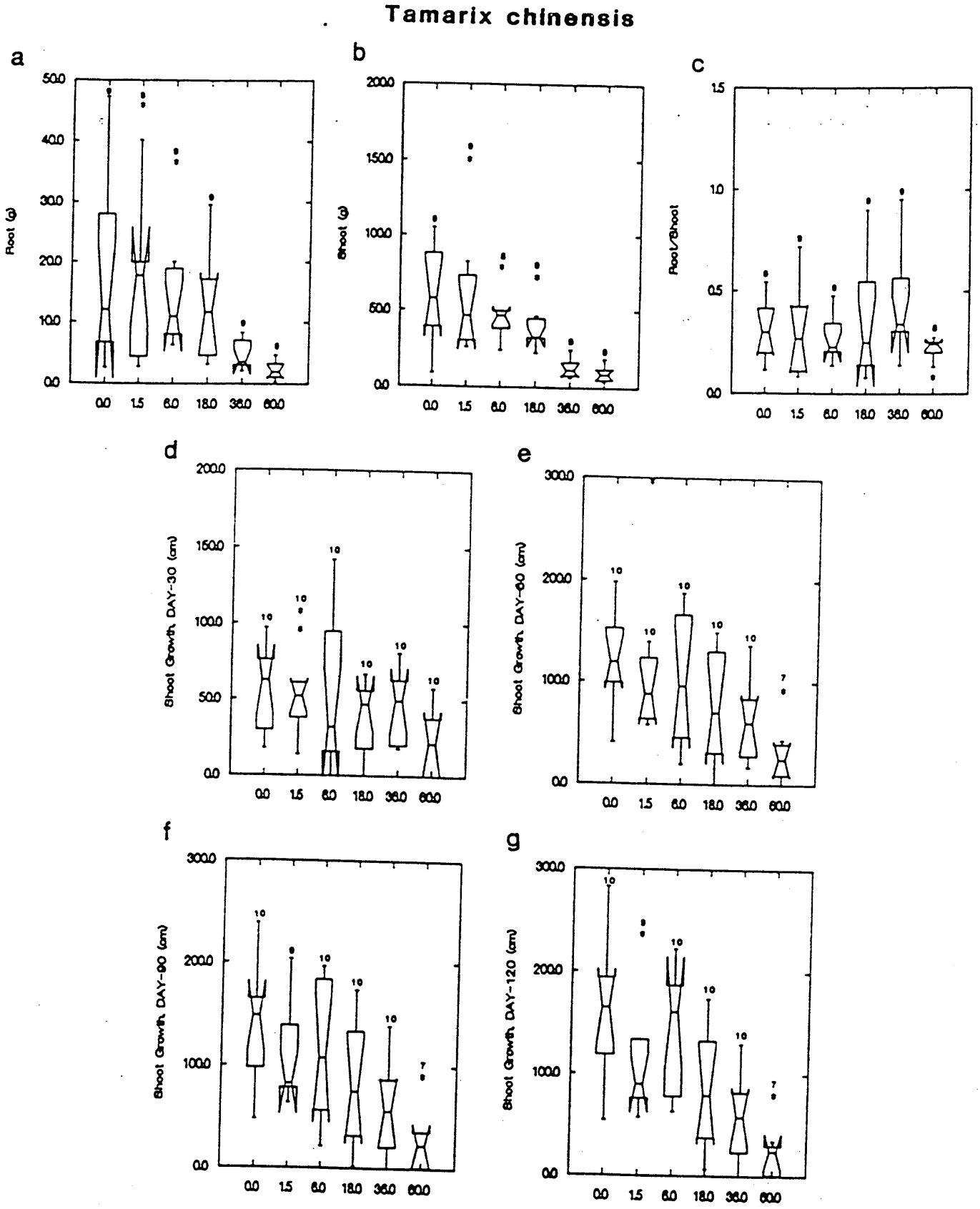


Figure 9

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Tamarix chinensis*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 13. Results of the ANOVA and multiple comparisons tests by growth variable for *Tamarix chinensis*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

13a

Variable = Root
ANOVA: $F_{5,48} = 3.810$; $p = .005$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	18.73	0.00					
1,500	18.12	0.60	0.00				
6,000	14.95	3.78	3.18	0.00			
18,000	12.16	6.56	5.96	2.78	0.00		
36,000	4.72	14.00	13.40	10.22	7.44	0.00	
60,000	2.27	16.46*	15.85*	12.67	9.89	2.45	0.00

13b

Variable = Shoot
ANOVA: $F_{5,48} = 6.260$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	60.59	0.00					
1,500	57.70	2.89	0.00				
6,000	58.53	2.06	-0.83	0.00			
18,000	39.02	21.57	18.68	19.52	0.00		
36,000	12.86	47.73**	44.84*	45.68*	26.16	0.00	
60,000	9.43	51.16**	48.27**	49.10**	29.59	3.42	0.00

13c

Variable = R/S
ANOVA: $F_{5,48} = 0.989$; $p = .434$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.30
1,500	0.32
6,000	0.27
18,000	0.35
36,000	0.42
60,000	0.23

Table 13. Results of the ANOVA and multiple comparisons tests by growth variable for *Tamarix chinensis* (cont.)

13d

Variable = Day-30
ANOVA: $F_{5,54} = 1.566$; $p = .185$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)
0	54.1
1,500	55.6
6,000	48.8
18,000	37.5
36,000	39.8
60,000	20.8

13e

Variable = Day-60
ANOVA: $F_{5,51} = 3.355$; $p = .011$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	118.4	0.0					
1,500	108.6	9.8	0.0				
6,000	99.0	19.4	9.6	0.0			
18,000	76.0	42.4	32.6	23.0	0.0		
36,000	61.1	57.3	47.5	37.9	14.9	0.0	
60,000	29.1	89.3*	79.4*	69.9	46.9	31.9	0.0

13f

Variable = Day-90
ANOVA: $F_{5,51} = 4.460$; $p = .002$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	143.6	0.0					
1,500	126.4	17.2	0.0				
6,000	115.3	28.3	11.1	0.0			
18,000	82.0	61.6	44.4	33.3	0.0		
36,000	57.4	86.2*	69.0	57.9	24.6	0.0	
60,000	24.9	118.7**	101.5*	90.4	57.1	32.5	0.0

Table 13. Results of the ANOVA and multiple comparisons tests by growth variable for *Tamarix chinensis* (cont.)

13g

Variable = Day-120
ANOVA: $F_{5,51} = 6.240$; $p = .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	160.8	0.0					
1,500	129.9	30.9	0.0				
6,000	144.7	16.1	-14.8	0.0			
18,000	84.0	76.8	45.9	60.7	0.0		
36,000	55.0	105.8**	74.9	89.7*	29.0	0.0	
60,000	21.6	139.2**	108.3*	123.1**	62.4	33.4	0.0

response was greater at 6,000 mg/l than at 60,000 mg/l. *Tamarix* has indeterminant leaves, therefore mean leaf surface area measurement was not applicable to this species.

Tessaria sericea. Growth response analyses in *Tessaria* indicated reduced growth as a function of increasing salinity. Reduced shoot and root biomass were evident in the 36,000 and 60,000 mg/l groups (Figure 10a and b), and shoot length increases appeared to decline as salinity increased to 36,000 mg/l. One hundred percent mortality occurred prior to Day-60 in the 60,000 mg/l group.

ANOVA and multiple comparisons tests indicated no significant differences in *Tessaria* shoot or root biomass among the four lowest salinity levels (Table 14). Root and shoot biomass within the 36,000 or 60,000 mg/l groups, however, was significantly less than in the 0 or 1,500 mg/l groups. Stem length increases throughout the experiment were significantly less in the 18,000 mg/l and 36,000 mg/l groups than in the 0, 1,500 or 6,000 mg/l groups. Mean leaf areas of *Tessaria* exhibited measurable decreases with increasing salinity.

Spectral Reflectance

The results of the spectral reflectance analysis are presented in Figures 11 and 12. The objectives of this analysis were to illustrate a shift in the red edge as a function of salinity, and to determine whether this shift is a precursor to morphological stress. Representative data are presented for each species to demonstrate the validity of spectral reflectance as either an indicator of morphological plant stress or as a predictive indicator of future morphological plant stress.

Shifts in the red edge of the spectral reflectance curve are typically subtle, and not obviously apparent with examination of the curve of spectral reflectance versus wavelength. Therefore, the first derivative was calculated for reflectance data between 680 and 740 nanometers wavelength to detect the instantaneous rate of change in reflectance as a function of wavelength along the slope of the red edge. This conversion provided a more intuitive indicator of the overall red edge shift indicating stress as a function of salinity.

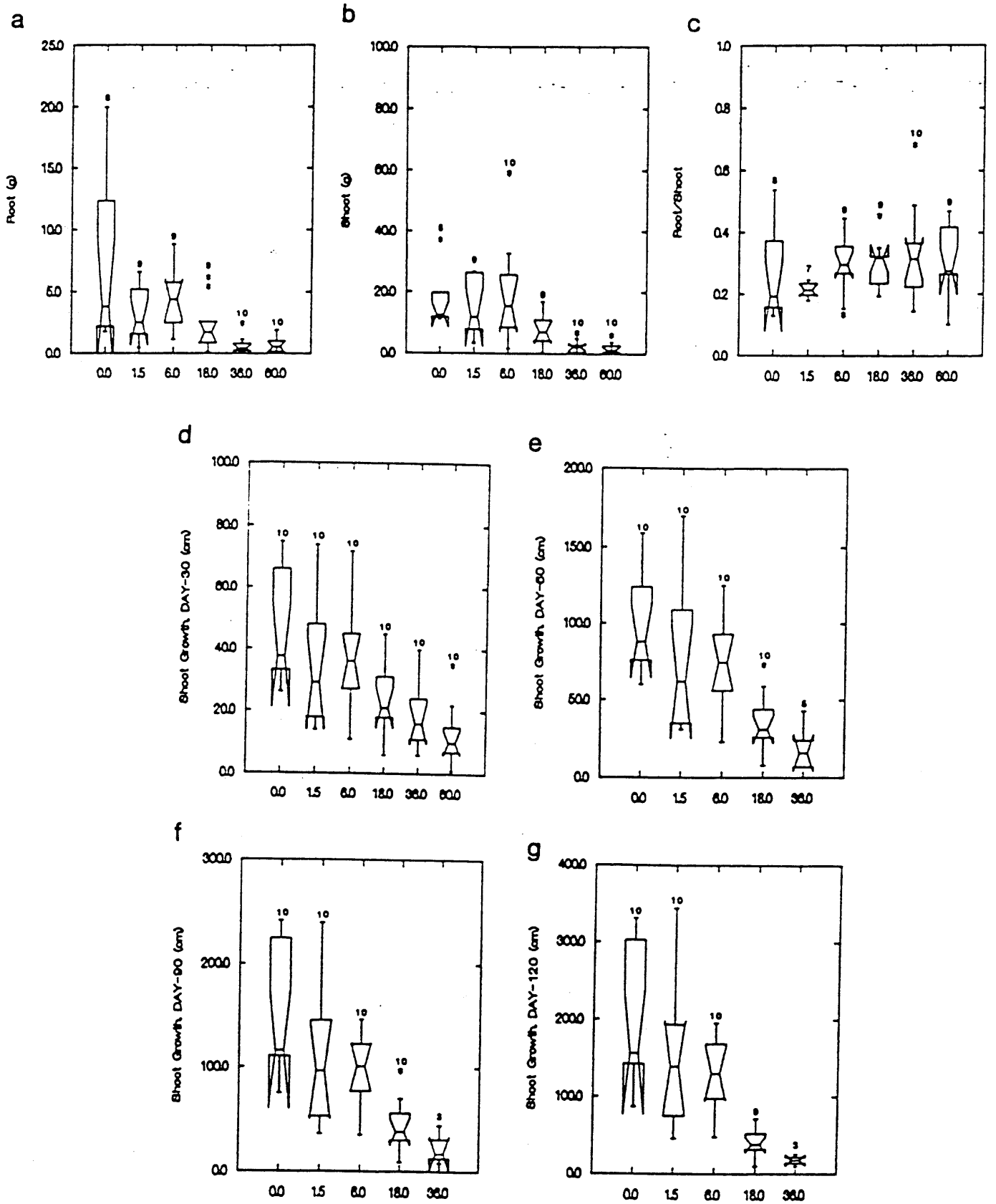


Figure 10

Box-and-Whisker diagrams displaying descriptive statistics for seven growth variables measured for the analysis of salinity tolerance of *Tessaria sericea*. Units of the X-axis are in grams per liter. Sample sizes are denoted atop each diagram.

Table 14. Results of the ANOVA and multiple comparisons tests by growth variable for *Tessaria sericea*. Pairwise comparisons are not illustrated for non-significant ANOVAs (* = $P \leq .05$; ** = $P \leq .01$)

14a

Variable = Root
ANOVA: $F_{5,51} = 2.694$; $p = .031$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Root Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	12.01	0.00					
1,500	3.23	8.77	0.00				
6,000	6.34	5.66	-3.11	0.00			
18,000	2.38	9.62	0.85	3.96	0.00		
36,000	0.68	11.33*	2.56	5.67	1.70	0.00	
60,000	0.70	11.31*	2.54	5.65	1.69	-0.02	0.00

14b

Variable = Shoot
ANOVA: $F_{5,51} = 4.818$; $p = .001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Biomass (g)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (g)					
0	25.45	0.00					
1,500	15.37	10.08	0.00				
6,000	19.88	5.57	-4.51	0.00			
18,000	7.75	17.67	7.61	12.13	0.00		
36,000	2.41	23.04**	12.96	17.47	5.35	0.00	
60,000	1.85	23.60**	13.51	18.03*	5.90	0.56	0.00

14c

Variable = R/S
ANOVA: $F_{5,51} = 0.747$; $p = .592$
Null Hypothesis: Accept

Salinity (mg/l)	$\bar{X}$ R/S
0	0.73
1,500	0.23
6,000	0.33
18,000	0.30
36,000	0.33
60,000	0.44

Table 14. Results of the ANOVA and multiple comparisons tests by growth variable for *Tessaria sericea* (cont.)

14d

Variable = Day-30
ANOVA: $F_{5,54} = 6.786$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-30 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	60,000
		Pairwise Mean Differences (cm)					
0	45.5	0.0					
1,500	34.1	10.3	0.0				
6,000	37.6	5.9	-4.4	0.0			
18,000	24.7	15.0	4.7	9.1	0.0		
36,000	19.2	16.5*	6.2	10.6	1.5	0.0	
60,000	12.3	20.4**	10.1	14.5	5.4	3.9	0.0

14e

Variable = Day-60
ANOVA: $F_{4,40} = 7.316$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-60 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	
		Pairwise Mean Differences (cm)					
0	98.4	0.0					
1,500	78.1	20.3	0.0				
6,000	74.8	23.6	3.3	0.0			
18,000	36.7	61.7*	41.4	38.1	0.0		
36,000	19.4	79.0**	58.7*	55.4**	17.3	0.0	

14f

Variable = Day-90
ANOVA: $F_{4,38} = 7.089$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-90 (cm)	Salinity (mg/l)					
		0	1,500	6,000	18,000	36,000	
		Pairwise Mean Differences (cm)					
0	148.9	0.0					
1,500	115.7	33.2	0.0				
6,000	98.5	50.4	17.2	0.0			
18,000	44.6	104.3*	71.1*	53.9	0.0		
36,000	23.0	125.9**	92.7**	75.5*	21.6	0.0	

Table 14. Results of the ANOVA and multiple comparisons tests by growth variable for *Tessaria sericea* (cont.)

14g

Variable = Day-120
ANOVA: $F_{4,38} = 7.910$; $p < .0001$
Null Hypothesis: Reject

Salinity (mg/l)	$\bar{X}$ Shoot Growth Day-120 (cm)	Salinity (mg/l)				
		0	1,500	6,000	18,000	36,000
		Pairwise Mean Differences (cm)				
0	198.3	0.0				
1,500	161.5	36.8	0.0			
6,000	130.4	67.9	31.1	0.0		
18,000	46.9	151.4*	114.6**	83.5	0.0	
36,000	18.0	180.3**	143.5**	112.4*	28.9	0.0

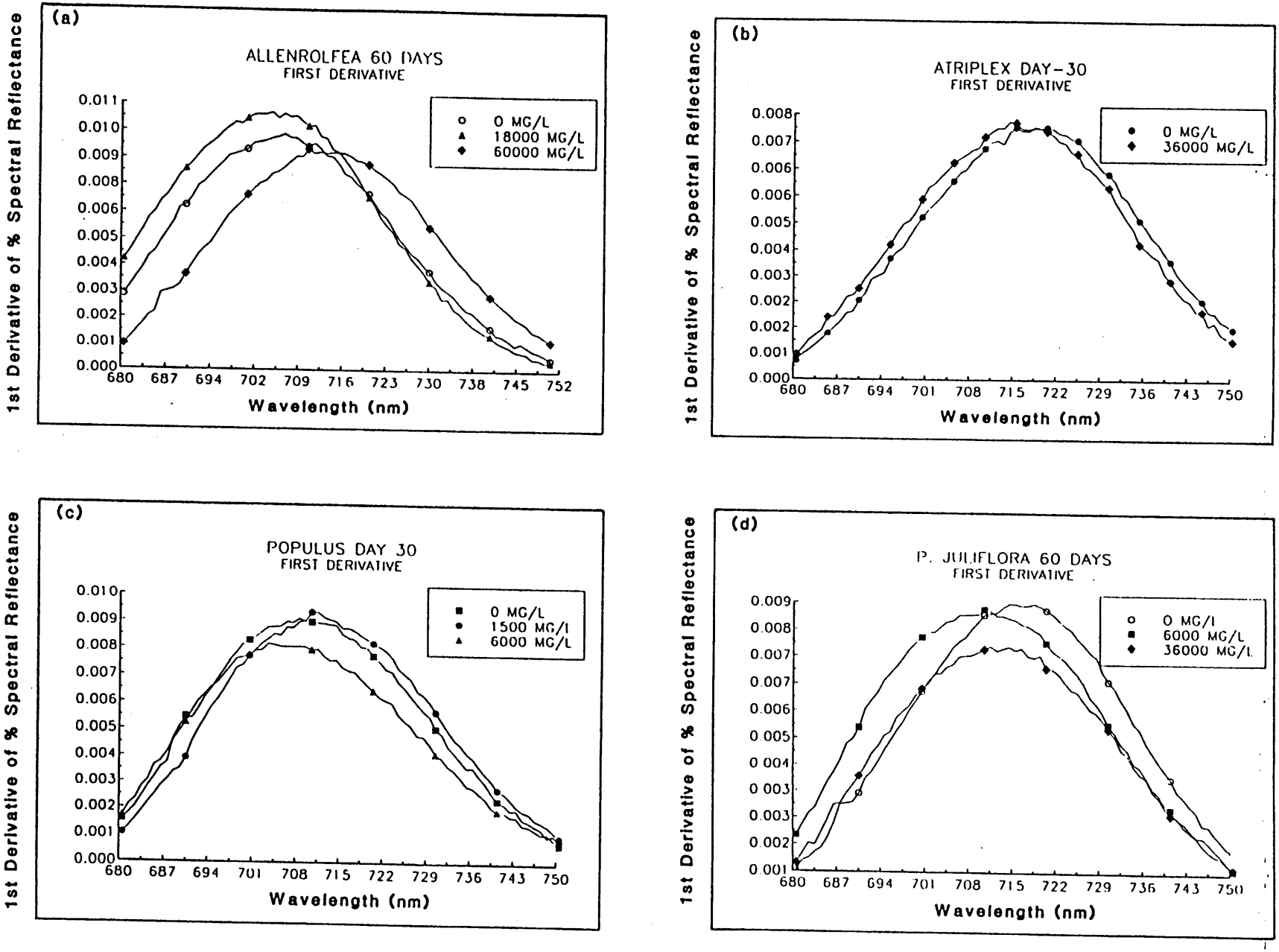
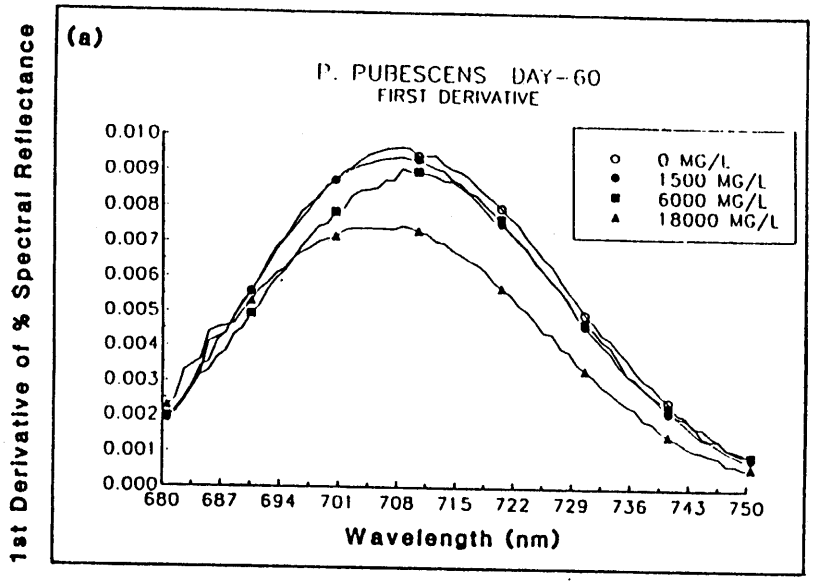
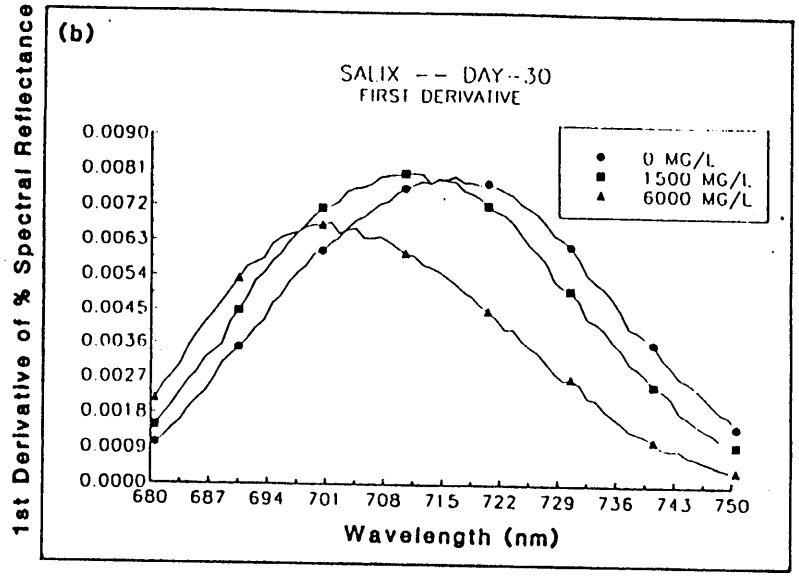
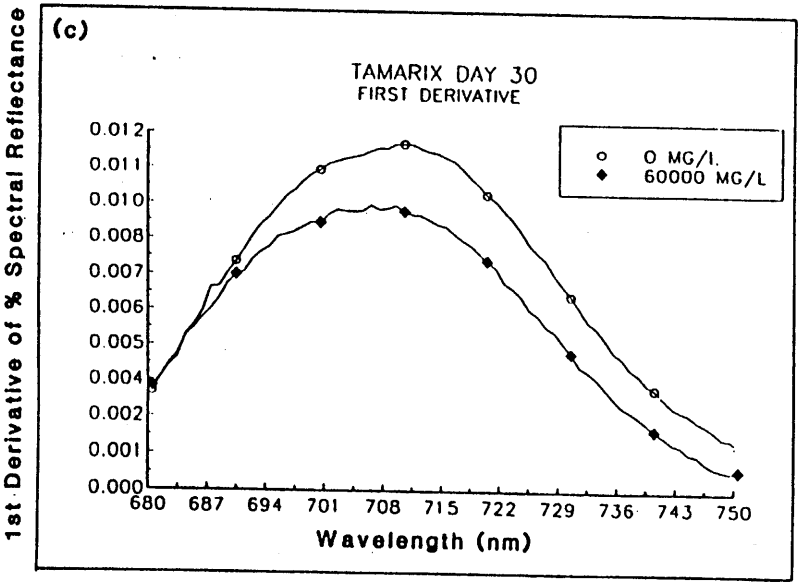


Figure 11

First derivative of percent spectral reflectance on the "red edge" of the electromagnetic spectrum for *Allenrolfea*, *Atriplex*, *Populus*, and *P. juliflora*.







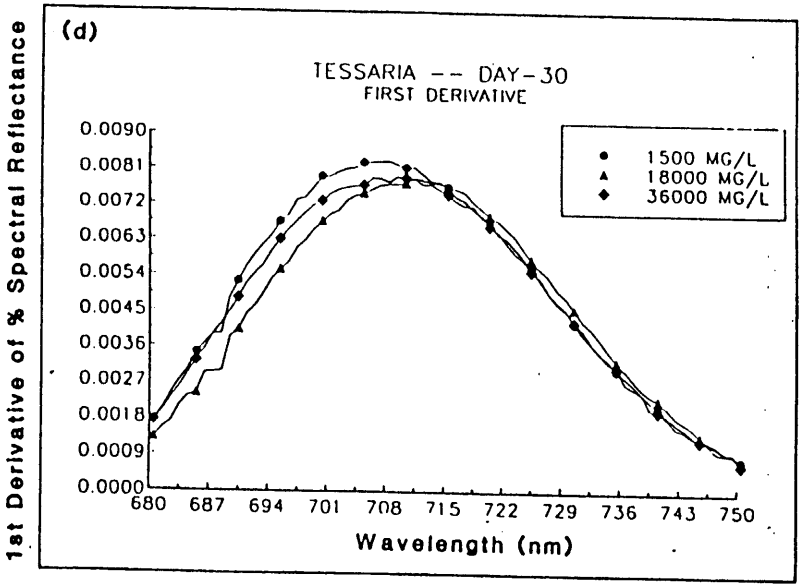


Figure 12

First derivative of percent spectral reflectance on the "red edge" of the electromagnetic spectrum for *P. pubescens*, [illegible], *Tamarix*, and *Tessaria*.

In general, the derivative curves generated from reflectance measurements of green leaves for plants growing at higher salinity levels are lower and peak at different wavelengths than curves derived from plant materials growing under lower salinities. For example, the derivatives peaks of the spectra generated from *Allenrolfea*, *Populus*, *P. juliflora*, *P. pubescens*, *Salix* and *Tamarix* leaf materials are lower at higher salinity levels, and located at lower (*Allenrolfea*) or higher wavelengths (*Populus*, *P. pubescens*, *Salix* and *Tamarix*) than curves of plants growing at lower salinities. Comparisons of the spectral reflectance curves with morphological data collected in the following time interval for each species further illustrates the utility of spectral reflectance measurement. The results of individual species comparisons are presented below.

Allenrolfea occidentalis. Spectral reflectance curves of *Allenrolfea* leaves at Day-60 (Figure 11) indicate that plants grown at 0 mg/l generate a curve intermediate in both wavelength position and derivative peak to plants grown at either 18,000 mg/l or 60,000 mg/l. The morphological data from Day-60 (Figure 4e) indicate that morphological responses are higher at intermediate salinity levels. Predictive capabilities of spectral reflectance were not substantiated by comparisons with Day-60, -90, or -120 morphological growth in this species since the statistical analyses for these variables were not significant (Table 8). It is therefore not possible to determine whether spectral reflectance is actually pre-determining morphological stress or decreased growth rates.

Atriplex lentiformis. Comparisons of reflectance data derived from measurement of *Atriplex* leaves at Day-30 (Figure 11b) were compared with morphological data from Day-60 to determine the utility of spectral reflectance measurements as an indicator or predictor of stress in this species. Morphological growth in the 0 mg/l group was significantly different than in the 36,000 mg/l group on Day-60, but not on Day-30 (Table 7d and e). The Day-30 curves for 0 mg/l and 36,000 mg/l salinity levels did not provide a predictor of morphological growth reductions at Day-60. Other reflectance data for the species do show an indicator response, however. Comparisons of morphological data and reflectance

curves at Day-120 (not illustrated) demonstrated that the curves respond to increased salinity by either lowering or shifting of the derivative peak to higher wavelengths.

Populus fremontii. Reflectance measurements of *Populus* leaves taken at Day-30 suggest different responses for plants grown at 6,000 mg/l than at 0 mg/l or 1,500 mg/l. Differences in growth response based on morphological data from Day-30 are not apparent (Figure 5d, Table 9). However, the morphological data from Day-60 (Figure 5e, Table 9) indicate that *Populus* grown at 6,000 mg/l exhibits a lower growth rate than at the lower salinity levels. Furthermore, percent survival of *Populus* at 6,000 mg/l by the end of the experiment was 0 percent (Table 5).

Prosopis juliflora* var. *torreyana. Spectral reflectance curves at Day-60 (Figure 11d) indicate the lowering and shift to lower wavelengths of the derivative peak with increasing salinity. Morphological data collected on Day-60 similarly indicate a trend towards decreased growth at higher salinity levels (Figure 6e), however the multiple comparison test did not show which groups were different (Table 10). The predictive use of reflectance data was thus not shown with this comparison. Comparisons of spectral reflectance at Day-30 with the morphological data at Day-90 are somewhat nebulous since the morphological growth responses did not reveal significant differences in growth response. Spectral reflectance for plants on Day-120 (not illustrated) indicate a substantially lower reflectance peak and larger shift to lower wavelengths at higher salinity levels. These data are possibly indicative of stress response pre-manifested through spectral reflectance for individuals grown at higher salinity levels.

Prosopis pubescens. Spectral reflectance curves for *P. pubescens* indicate a response similar to that of *P. juliflora*. The derivative peak appears to lower with increasing salinity up to 18,000 mg/l (Figure 12a). This response could not be tracked at higher salinity levels because leaves had started to abscise (presumably in response to salt stress). Comparisons between reflectance at Day-60 and stem length data at Days 60, 90, and 120 suggest that morphological growth responds similarly (Figure 7e, f, and g; Table 11). The utility of spectral reflectance for predicting growth responses to stress can not be

determined based on this data alone. Reflectance data at Day-90 and Day-120 (not illustrated) demonstrate stress response in lowering and shifting of the derivative peaks to shorter wavelengths, thus the data does provide a useful indicator of stress.

Salix gooddingii. Analyses of the reflectance curves derived for *Salix* at Day-30 indicated that the derivative peak of spectral reflectance for the 6,000 mg/l was substantially lower and exhibited a shift to shorter wavelengths than the peaks for 0 mg/l or 1,500 mg/l (Figure 12c). This response was similar to that of *Populus* (Figure 11c). Morphological growth responses in the 6,000 mg/l group were not detectable either graphically or statistically at Day-30 (Figure 8d, Table 12). Morphological response of the 6,000 mg/l group was exceptionally low by Day-60 (Figure 8e, Table 12e). Comparison of spectral reflectance and morphological data from Day-60 indicated reflectance provided a predictor of stress growth responses prior to occurrence of actual morphological responses.

Tamaris chinensis. Examination of spectral reflectance of *Tamarix* on Day-30 indicate that the derivative peak at 60,000 mg/l is noticeably lower than the 0 mg/l peak (Figure 12c). Morphological data from Day-30 do not indicate statistically differences in growth response between any salinity level. Growth response on Day-60, however, shows a significant difference in growth response between these two salinity groups. This comparison suggests that spectral reflectance data does provide an early indicator of lower morphological growth response with increasing salinity.

Tessaria sericea. Reflectance data from the 1,500, 18,000 and 36,000 mg/l groups on Day-30 were examined to determine the potential for predicting morphological stress in *Tessaria*. Morphological data from Day-30 did not indicate differences in growth response at these salinity levels (Figure 10d, Table 14d), however, significant differences were found at Day 60 and 90 (Figure 10e and f; Table 14e and f). Shifts in the derivative curves were not succinct enough to suggest predictive responses in this species. Reflectance data on Days 60 and 90 also did not satisfactorily indicate predictive capabilities for this species.

Photosynthetic Responses

In the proposal submitted for the present work we suggested that measurement of photosynthetic CO_2 assimilation rates might be a useful indicator of salt stress. In particular, it was pointed out that fixed carbon is needed for growth and therefore, it was likely that reductions in plant growth were likely to be proceeded by reductions in photosynthetic rates. On this basis, a program was set up to measure photosynthesis for each species at each salinity on a regular basis. The Li-Cor 6200 portable photosynthesis system is widely used to screen agricultural species and is also used to a limited extent in physiological studies of wildland species. The system is a non-steady state, that is, a transient measuring system. Leaf material is clamped into a Plexiglas chamber and the change in chamber water vapor and CO_2 content per unit time is the basis for calculating the CO_2 assimilation and transpiration rates and stomatal conductance.

This system has several disadvantages and several advantages relative to other kinds of systems for measuring photosynthesis and transpiration (see Field et al.1989 for an in depth discussion). The main advantage to the Li-Cor system is that it allows measurements to be made quickly (about one every 10 minutes when moving between plants whereas steady-state systems for which the conditions that the leaf is exposed to are fully controlled may require as much as an hour to move between measured leaves.) Li-Cor system measurements contain the assumption that leaves are operating near steady-state and that the chamber does not have a significant impact upon the condition of the air or the leaf. Normally this system gives only a limited amount of information to the operator (two variables) to allow judgment as to the quality of the data. Good steady-state systems normally report fully, on the status of the leaf and environmental variables which may influence the leaf.

In general, we found screening wildland species, under greenhouse conditions to be disappointingly difficult, time consuming, and quite prone to erroneous measurements. Particular problems included errors in leaf area measurement, inability to determine if the chamber was adequately sealed, temporally and spatially variable environmental

conditions and leaf responses. All of these problems are exaggerated by the fact that it is difficult to assess the data quality while the measurements are being made.

The potential problems mentioned above made it necessary to carefully screen that data which one obtains with the Li-Cor system. Screening was based on the following: sequential values during a measurement must have changed in a consistent fashion, and values should have been reasonable, relative to gas exchange data from similar species in the literature and measurements from steady state systems. Experience indicates that among the best criteria for judging the validity of gas exchange data are the relationships of photosynthesis to stomatal conductance and transpiration rate. Unfortunately, we found that a good deal of our data was not usable due mainly to fluctuating and/or low light intensities. In order to report a significant quantity of data here we were forced to reduce our normal standards for accepting data. The effect of this reduction shows up as what we would normally consider an unacceptably high variance (or standard deviation) in photosynthetic rates. Our sample size was large and we repeated many of the measurements but the progressive nature of the experiment constrained the extent of remeasuring that we were able to do.

The results of the photosynthetic measurements presented in Tables 15 - 20 and illustrated in Figures 13-18 should be interpreted with special caution. These tables and figures illustrate trends in photosynthesis but the absolute values of the mean values have a good deal of uncertainty attached. The bar charts presented in the figures do not include error bars because they make the graphs difficult to grasp. The Student's T-test at the 90% confidence interval was engaged to test for statistically significant differences between two sample means with a sample size of three (the most commonly reported number of samples), by determining if the means plus 2.92 times their standard deviations overlaped (one tailed test). From even a casual perusal of the mean photosynthetic rates and associated standard deviation values (Tables 15-20) it becomes clear that mean values of adjacent salinity levels and time points are rarely of statistical significance. The figures illustrating photosynthetic rate (13-18) also make it clear that there was a strong

time-related reduction of photosynthetic rates. The experiment was conducted in late summer through autumn so that this time dependent factor was most likely photoperiod and/or total daily photon flux. We can not, however, rule out the possibility that declining

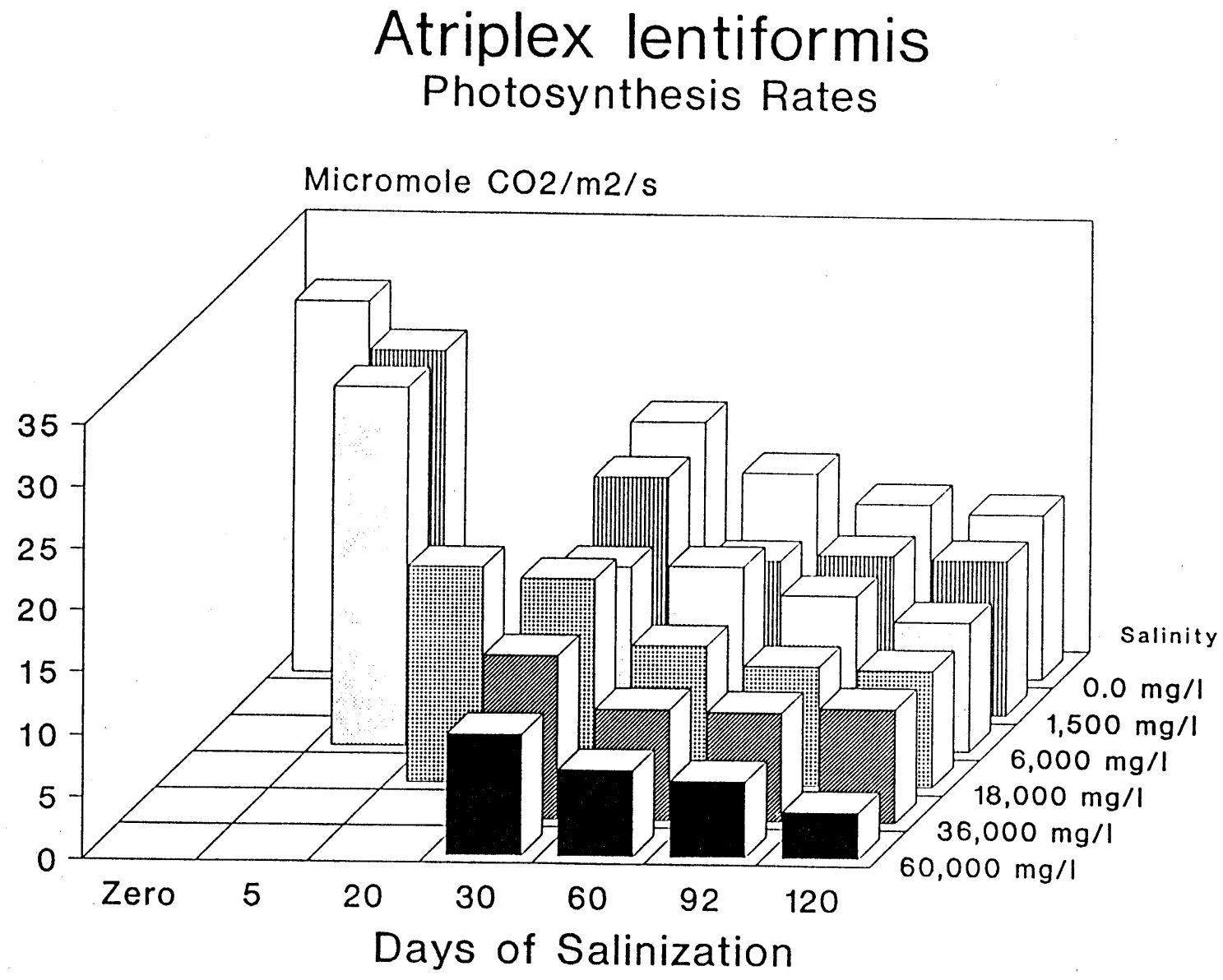


Figure 13

Photosynthesis rate (micromole $CO_2/m_2/s$) for *Atriplex lentiformis* over 120 days of salinization

Table 15. Photosynthetic rate (micromole/meter^2/second) for *Atriplex lentiformis*

Salinity Level (mg/l)	Days After Commencement of Salinization						
	0	3–5	15–20	29–30	58–62	88–92	115–120
0	29.1	N	N	20.3	15.1	15.0	12.9
	32.3	N	N	19.7	16.9	12.4	14.1
	29.8	N	N	20.2	17.6	14.9	13.1
	31.2			22.2			
	28.1						
	28.7						
	32.4						
	29.3						
Mean	30.1			20.6	16.5	14.1	13.4
S. Dev	1.5			1.0	1.1	1.2	0.5
1.500		28.4	N	19.4	13.2	14.2	12.9
		29.8	N	18.0	11.6	11.1	10.6
		29.2	N	19.5	12.2	13.2	13.9
Mean		29.1		19.0	12.3	12.8	12.5
S. Dev		0.6		0.7	0.7	1.3	1.4
6.000		29.2	N	15.7	14.6	12.0	12.0
		27.7	N	13.8	15.0	13.4	8.8
		30.2	N	14.4	14.4	11.9	10.0
Mean		29.0		14.6	14.7	12.4	10.3
S. Dev		1.0		0.8	0.2	0.7	1.3
18.000		U	17.6	16.5	11.4	10.0	7.7
		U	16.7	17.0	11.3	9.3	10.7
		U	17.8	16.0	10.5	9.2	9.5
			18.4				
			16.7				
Mean			17.4	16.5	11.1	9.5	9.3
S. Dev			0.7	0.4	0.4	0.4	1.2
36.000		U	U	12.2	9.2	9.9	8.0
		U	U	14.3	8.0	7.9	10.8
		U	U	12.9	9.5	8.4	8.6
		U	U				9.0
Mean				13.1	8.9	8.7	9.1
S. Dev				0.9	0.6	0.8	1.2
60.000		U	U	9.3	7.5	6.5	4.9
		U	U	10.0	6.1	5.8	3.8
		U	U	9.9	7.0	6.0	2.5
				9.4			
Mean				9.7	6.9	6.1	3.7
S. Dev				0.3	0.6	0.3	1.0

LEGEND: N = not measured; U = unavailable

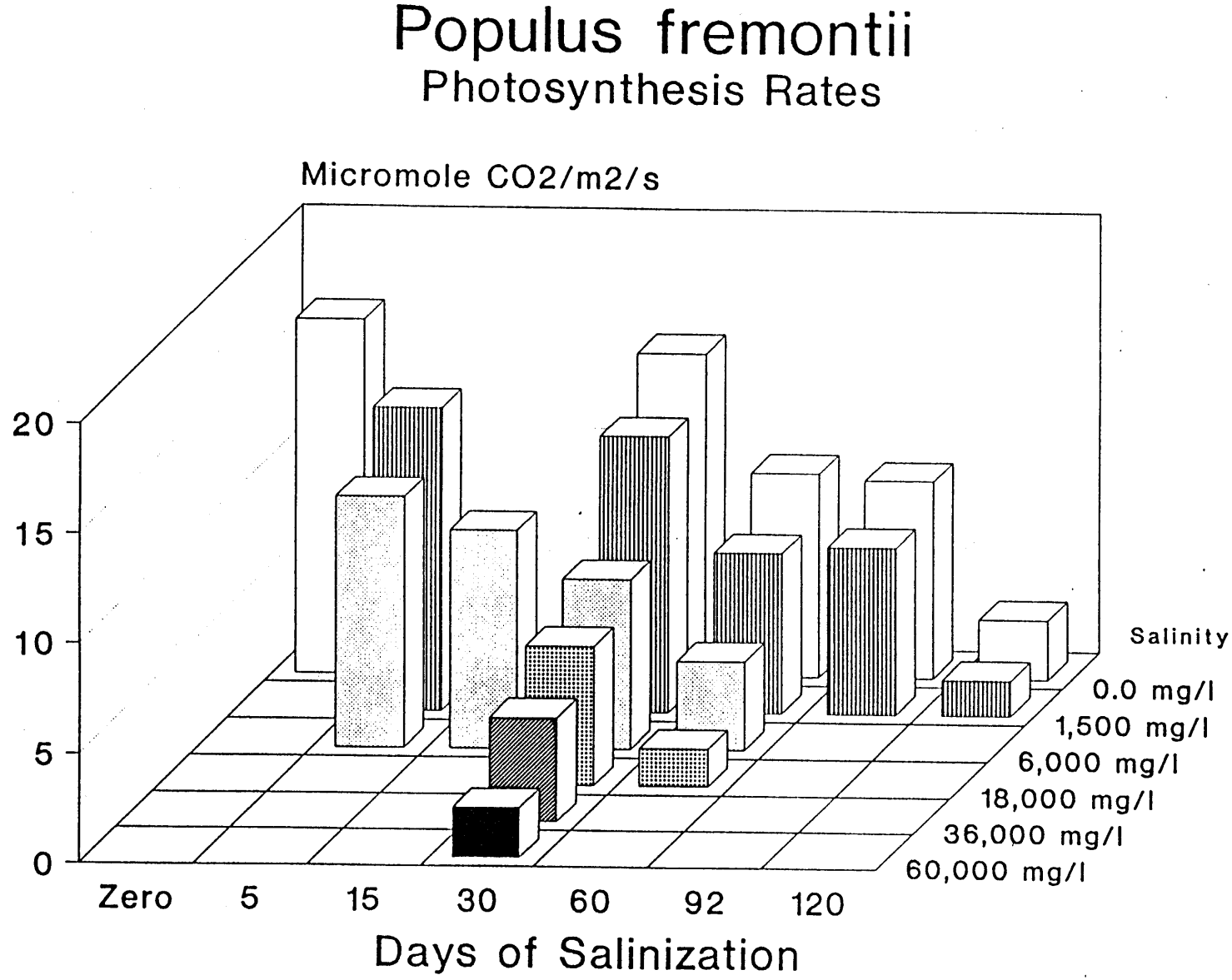


Figure 14

Photosynthesis rate (micromole $CO_2/m_2/s$) for *Populus fremontii* over 120 days of salinization

Table 16. Photosynthetic rate (micromole/meter^2/second) for *Populus fremontii*

Salinity Level (mg/l)	Days After Commencement of Salinization						
	0	3–5	10–15	26–29	58–62	87–91	115–120
0	15.8	N	N	16.3	9.4	8.6	2.4
	15.2	N	N	13.9	10.1	9.0	3.0
	15.1	N	N	14.0	8.9	9.4	D
	14.7			14.5	8.7		
	16.0						
	15.9						
	16.9						
	17.4						
	17.9						
Mean	16.1			14.7	9.3	9.0	2.7
S. Dev	1.0			1.0	0.5	0.3	1.3
1.500		14.8	N	13.6	6.7	7.5	1.8
		13.5	N	12.3	7.2	8.2	1.4
		13.0	N	11.9	7.9	7.1	
Mean		13.8		12.6	7.3	7.6	1.6
S. Dev		0.8		0.7	0.5	3.2	0.2
6.000		11.5	10.8	7.6	4.3	D	D
		10.9	9.8	8.3	4.0	D	D
		10.7	10.4	7.2	3.7	D	D
		12.3	8.7				
Mean		11.4	9.9	7.7	4.0		
S. Dev		0.3	0.4	0.5	0.2		
18.000		U	U	7.3	1.8	D	D
		U	U	6.1	2.0	D	D
		U	U	5.5	1.4	D	D
Mean				6.3	1.7		
S. Dev				2.6	0.7		
36.000		U	U	4.8	D	D	D
		U	U	5.4	D	D	D
		U	U	4.0	D	D	D
Mean				4.7			
S. Dev				1.0			
60.000		U	U	1.8	D	D	D
		U	U	2.4	D	D	D
		U	U	2.7	D	D	D
Mean				2.3			
S. Dev				0.6			

LEGEND: N = not measured; U = unavailable; D = dead or dormant

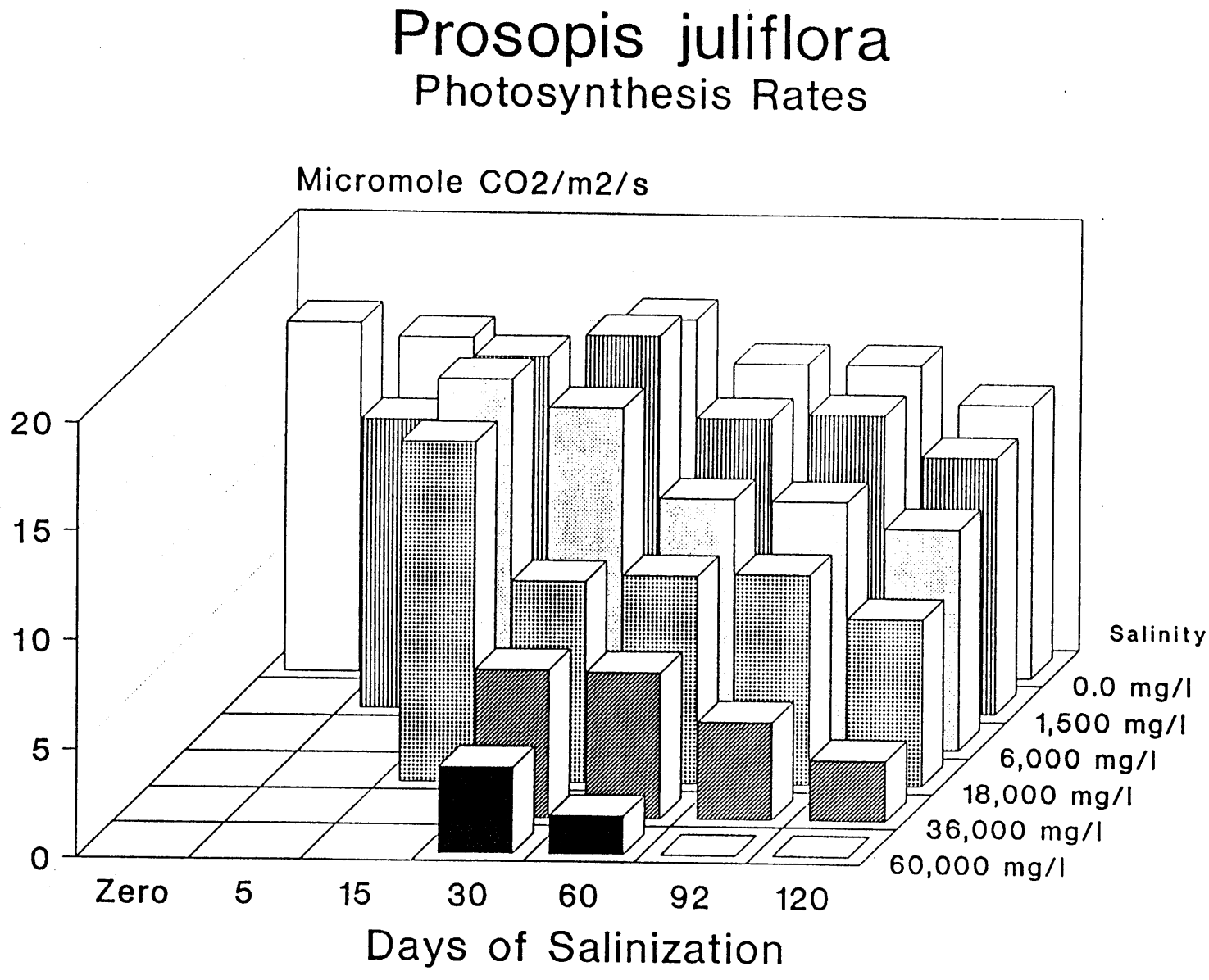


Figure 15

Photosynthesis rate (micromole $CO_2/m_2/s$) for *Prosopis juliflora* var. *torreyana* over 120 days of salinization

Table 17. Photosynthetic rate (micromole/meter^2/second) for *Prosopis juliflora* var. *torreyana*

Salinity Level (mg/l)		Days After Commencement of Salinization						
		0	3–5	10–15	29–30	58–62	88–92	115–120
0		16.2	15.8	N	17.0	14.6	15.0	13.2
		18.4	14.1	N	16.3	13.7	13.7	12.7
		14.6	16.5	N	15.9	14.9	14.6	12.0
		14.5						
		17.1						
		16.0						
	Mean	16.1	15.5		16.4	14.4	14.4	12.6
	S. Dev	1.4	1.0		0.5	0.5	0.5	0.5
1.500			12.5	16.7	16.3	12.5	12.3	11.9
			14.2	15.9	18.2	13.9	14.0	12.7
			13.9			14.0	14.9	10.8
			12.7					
	Mean		13.3	16.3	17.3	13.5	13.7	11.8
	S. Dev		0.7	0.4	0.9	0.7	1.1	0.8
6.000			U	17.0	16.3	12.0	12.0	9.6
			U	16.8	17.1	10.5	10.8	11.2
					13.3	11.7	11.0	9.6
	Mean			16.9	15.6	11.4	11.3	10.1
	S. Dev			0.1	1.6	0.6	0.5	0.8
18.000			U	14.9	9.8	11.0	12.3	8.2
			U	14.3	10.4	9.1	7.8	7.9
			U	17.3	7.4	8.3	8.8	6.6
				15.8				
	Mean			15.6	9.2	9.5	9.6	7.6
	S. Dev			1.3	1.3	1.1	1.9	0.7
36.000			U	U	7.4	8.5	4.1	3.2
			U	U	5.0	6.0	5.3	3.0
			U	U	7.9	5.7	4.1	2.3
	Mean				6.8	6.7	4.5	2.8
	S. Dev				1.3	1.3	0.6	0.4
60.000			U	U	3.2	1.8	0.0	0.0
			U	U	4.7	2.2	0.0	0.0
			U	U	4.0	1.5	0.0	0.0
	Mean				4.0	1.8	0.0	0.0
	S. Dev				0.6	0.3	0.0	0.0

LEGEND: N = not measured; U = unavailable

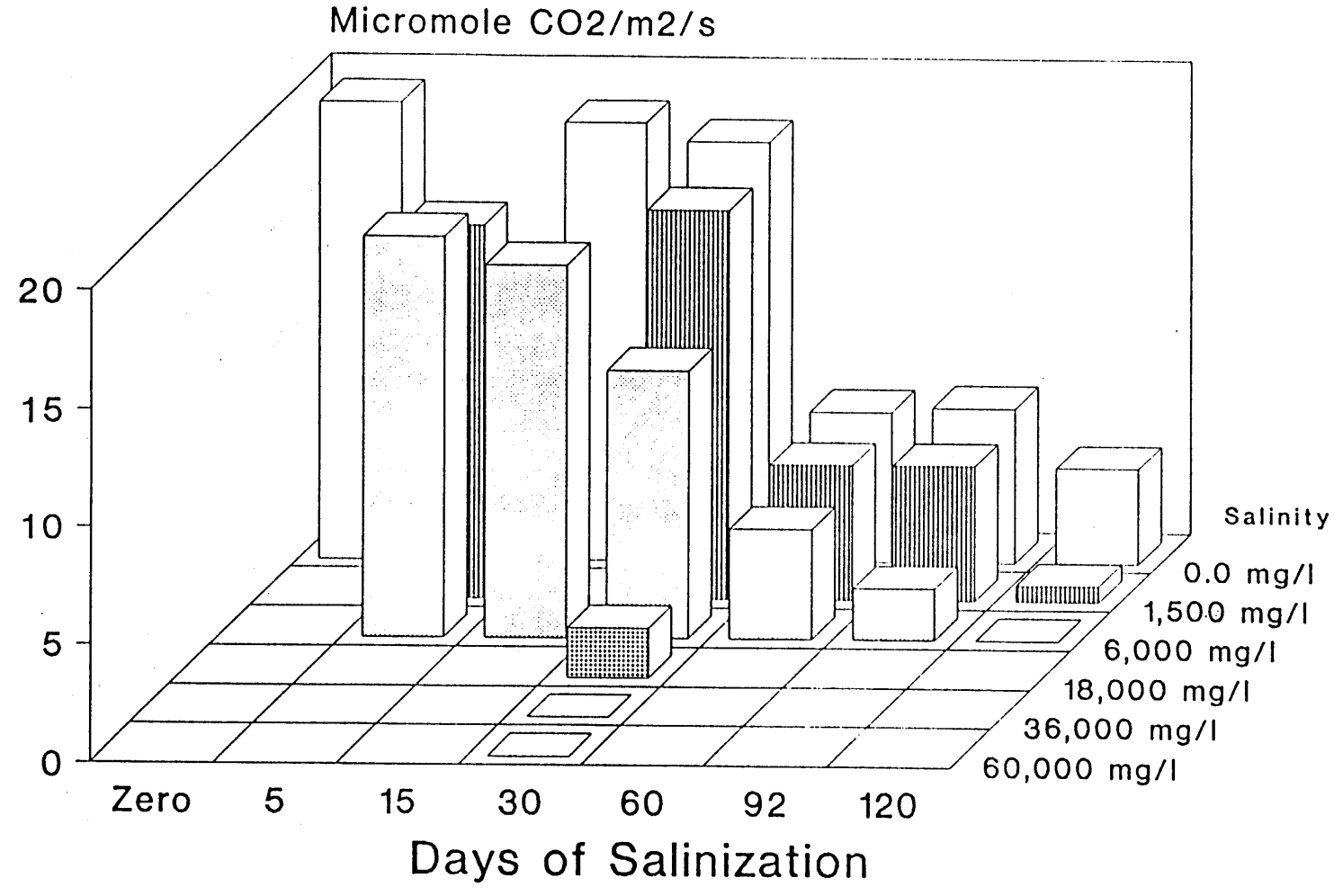


Figure 16

Photosynthesis rate (micromole $CO_2/m_2/s$) for *Salix gooddingii* over 120 days of salinization

Table 18. Photosynthetic rate (micromole/meter^2/second) for *Salix gooddingii*

Salinity Level (mg/l)		Days After Commencement of Salinization						
		0	3–7	10–15	29–30	58–62	88–92	115–120
0		19.9		19.9	18.7	6.9	6.9	4.3
		19.7		18.5	17.6	6.5	5.3	3.6
		19.5		17.0	16.2	5.7	6.7	4.4
		19.2			18.3		7.6	
		18.2						
	Mean	19.3		18.5	17.7	6.4	6.6	4.1
	S. Dev	0.6		1.2	1.0	0.5	0.8	0.4
1.500			16.9	N	16.5	7.6	6.6	1.1
			14.1	N	17.3	5.3	6.5	0.9
			16.5	N	15.8	4.5	4.3	0.0
			15.8			6.4		
	Mean		15.8		16.5	5.8	5.8	0.7
	S. Dev		1.1		0.6	1.3	1.1	0.5
6.000			17.3	16.5	12.3	5.4	3.0	0.0
			15.5	16.3	11.2	4.1	3.6	0.0
			17.5	14.5	10.6	4.7	D	D
			17.9					
	Mean		17.1	15.8	11.4	4.7	2.2	0.0
	S. Dev		0.9	0.9	0.7	0.5	1.6	0.0
18.000			U	U	2.5	D	D	D
			U	U	2.0	D	D	D
			U	U	1.9	D	D	D
	Mean				2.1			
	S. Dev				0.3			
36.000			U	U	0.0	D	D	D
			U	U	0.0	D	D	D
			U	U	0.0	D	D	D
	Mean				0.0			
	S. Dev				0.0			
60.000			U	U	0.0	D	D	D
			U	U	0.0	D	D	D
			U	U	0.0	D	D	D
	Mean				0.0			
	S. Dev				0.0			

LEGEND: N = not measured; U = unavailable; D = dead or dormant

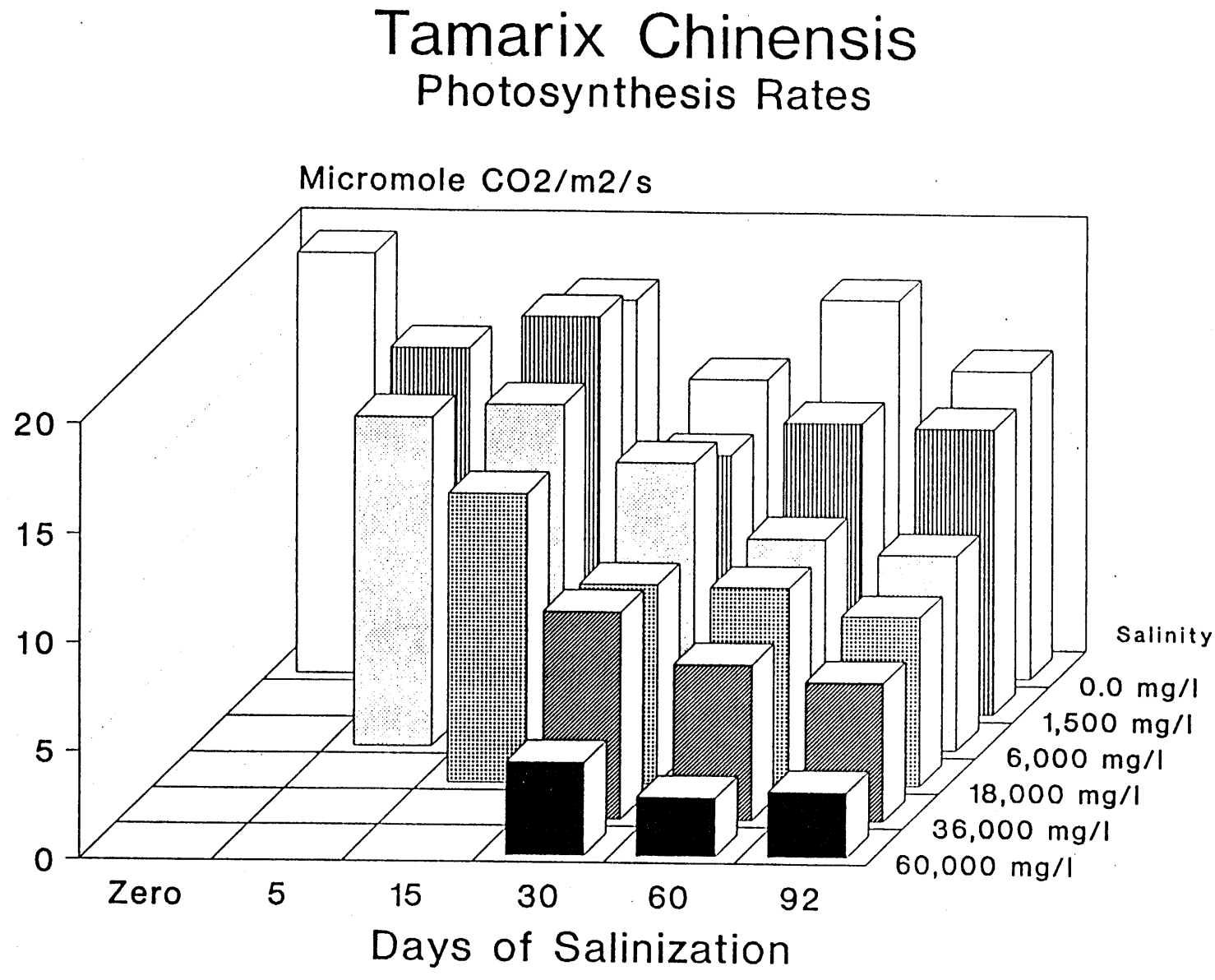


Figure 17

Photosynthesis rate (micromole $CO_2/m_2/s$) for *Tamarix chinensis* over 120 days of salinization

Table 19. Photosynthetic rate (micromole/meter^2/second) for *Tamarix chinensis*

Salinity Level (mg/l)	Days After Commencement of Salinization					
	0	3–5	10–15	29–30	58–62	88–92
0	17.1		17.0	14.0	17.3	13.1
	20.5		16.6	11.7	16.5	15.1
	17.7		18.1	15.2	18.0	
	19.5					
	19.4					
	21.6					
Mean	19.3		17.2	13.6	17.3	14.1
S. Dev	1.5		0.6	1.5	0.6	1.0
1.500		15.8	17.9	10.6	12.7	14.0
		16.8	18.2	12.9	13.3	12.2
		17.3			13.9	
Mean		16.6	18.1	11.8	13.3	13.1
S. Dev		0.6	0.2	1.2	0.5	0.9
6.000		13.7	17.3	13.0	9.5	8.5
		16.5	14.1	13.1	10.3	9.9
					9.4	8.7
Mean		15.1	15.7	13.1	9.7	9.0
S. Dev		1.4	1.6	0.0	0.4	0.6
18.000		U	11.2	9.8	8.7	9.2
		U	14.5	10.4	9.5	6.4
		U	14.3	7.4	9.0	7.8
Mean			13.3	9.2	9.1	7.8
S. Dev			1.5	1.3	0.3	1.1
36.000		U	U	8.4	8.5	8.3
		U	U	11.0	5.8	5.9
		U	U	9.4	7.2	4.9
Mean				9.6	7.2	6.4
S. Dev				1.1	1.1	1.4
60.000		U	U	3.2	2.8	2.0
		U	U	5.6	3.2	4.1
		U	U	4.0	2.0	3.0
Mean				4.3	2.7	3.0
S. Dev				1.0	0.5	0.9

LEGEND: U = unavailable

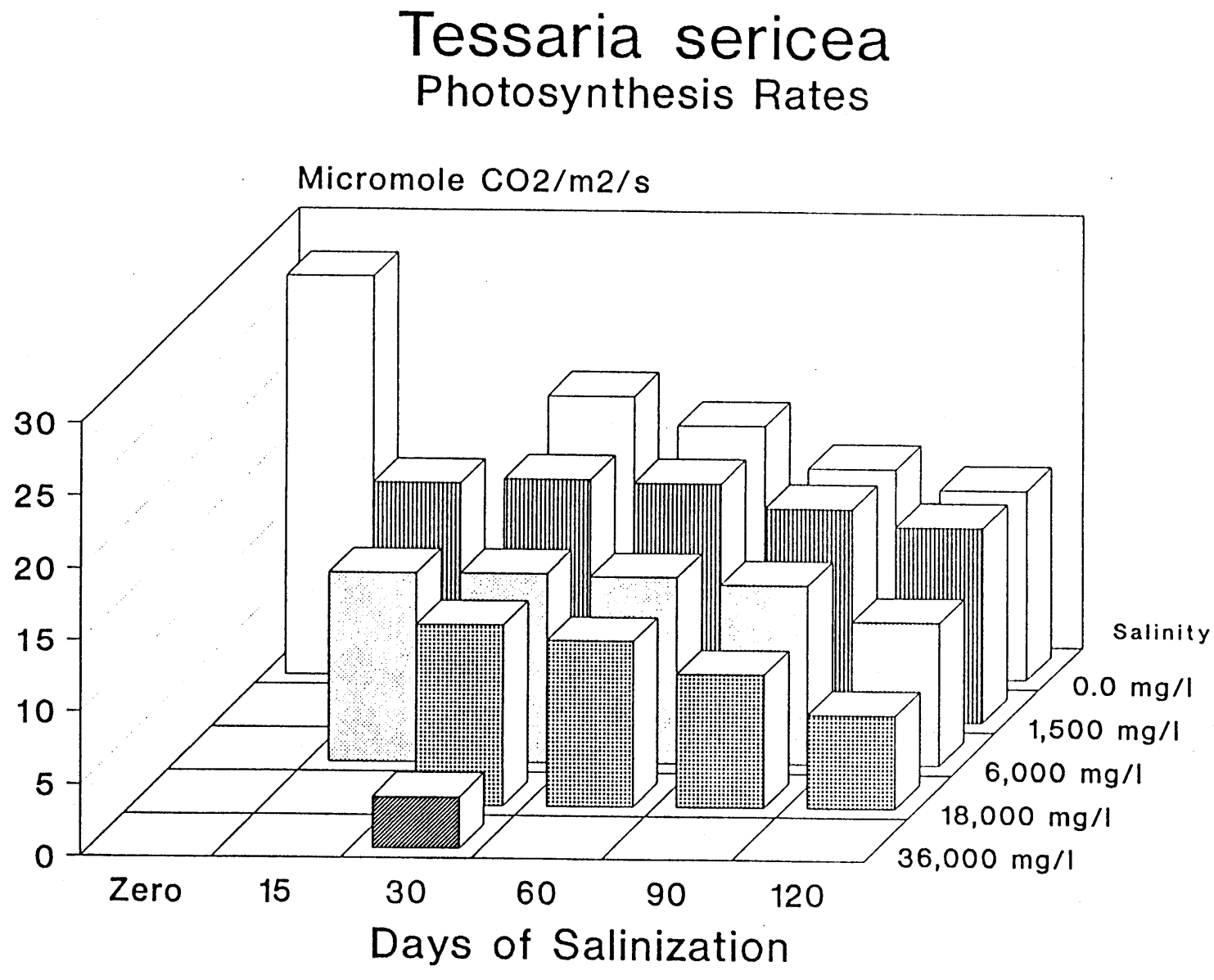


Figure 18

Photosynthesis rate (micromole $CO_2/m_2/s$) for *Tessaria sericea* over 120 days of salinization

Table 20. Photosynthetic rate (micromole/meter^2/second) for *Tessaria sericea*

Salinity Level (mg/l)	Days After Commencement of Salinization					
	0	10–15	29–30	58–62	88–92	115–120
0	26.3	N	20.1	17.2	13.9	12.1
	26.5	N	19.7	17.3	14.0	13.0
	29.0	N	18.6	18.1	16.0	14.4
	28.1					
	28.5					
	27.0					
	29.6					
	25.5					
Mean	27.6		19.5	17.5	14.6	13.2
S. Dev	1.4		0.6	0.4	1.0	0.9
1.500		17.8	17.1	15.9	14.7	14.0
		16.0	16.4	16.8	14.9	12.3
		16.6	16.7	16.8		14.4
		15.0				
Mean		16.4	16.7	16.5	14.8	13.6
S. Dev		1.0	0.3	0.4	0.1	0.9
6.000		12.8	14.0	13.1	14.0	10.9
		14.0	13.0	13.8	11.1	9.2
		13.6	13.3	12.0	12.5	9.9
		13.0	12.4			
		12.3				
		13.3				
Mean		13.2	13.2	13.0	12.5	10.0
S. Dev		0.5	0.6	0.7	1.2	0.7
18.000		U	12.7	11.2	9.8	7.4
		U	13.0	10.7	10.0	5.7
		U	12.2	12.5	7.7	6.1
Mean			12.6	11.5	9.2	6.4
S. Dev			0.3	0.8	1.1	0.7
36.000		U	3.5	D	D	D
		U	4.2	D	D	D
		U	3.0	D	D	D
Mean			3.6			
S. Dev			0.5			
60.000		U	D	D	D	D
		U	D	D	D	D
		U	D	D	D	D

LEGEND: N = not measured; U = unavailable; D = dead or dormant

mean temperature in the greenhouse was also partially responsible for this effect. It would appear that the seasonal effect was relatively uniform across all salinity levels but it appeared to have a much stronger effect on *Atriplex*, *Populus*, *Salix*, and *Tessaria* then on the other species. Note that the "Z" or vertical axis depicting photosynthetic rate extends to twenty for all species expect *Tessaria* and *Atriplex*.

Despite the difficulties which we have discussed there may be some important results to be noted from the trends in these data. Among the most salt sensitive plants, *Salix* and *Tessaria* appear to display sharp thresholds of tolerance where metabolic function collapses within fifteen days of exposure to the 18,000 mg/l salinity level for *Salix* and within eight days of reaching the 36,000 mg/l level for *Tessaria*. Thus, acute exposure episodes may be a particular problem in the management and survival of these two species. It appears that *Populus* may be slightly more tolerant of an acute salinity episode than *Salix* or *Tessaria* because *Populus* did have some photosynthetic capacity when exposed to 60,000 mg/l. Prolonged exposure to lower salinities had a stronger effect on the metabolic rates of *Salix* and *Populus* then on other species. This may be related to the fact that they are deciduous tree and this result has some danger of being complicated by the changing season. The two intermediately tolerant species *P. juliflora* and *Tamarix* were strongly affected by the highest salinity level but were both able to remain metabolically active for a significant period of time at that level. There is some indication in the data that time and intensity of the salinity treatments take a greater toll on the performance of *P. juliflora* while the metabolic rates of *Tamarix* may be more simply related to salinity level. We were unable to seal the chamber around the stems of two species in this study, *Allenrolfea* and *P. pubescens*. Thus we report no data on their photosynthetic rates.

Chlorophyll Fluorescence

Chlorophyll fluorescence is a biophysical process intimately associated with the light energy capturing portion of the photosynthetic carbon assimilation process. Fluorescence is the re-emission of energy in the form of light at a wavelength longer than the incoming wavelengths of light. The biophysics of this process are rather well characterized. Few

studies, however, have looked at chlorophyll fluorescence in an ecological context or as a potential tool for ecological research.

Within the last few years there has been a growing hope that chlorophyll fluorescence might be a useful indicator of the condition of plant in the field. Part of the hope for developing a new tool for measuring plant health via fluorescence was based on the collaboration of one of us (Ball) with several other scientists. One aspect of that work showed that chlorophyll fluorescence could be used to calculate relative photosynthetic rates (Weis et al. 1987, Weis and Berry 1987, Daley et al. 1989). From this work the possibility arose that remote sensing of chlorophyll fluorescence could be used to determine photosynthetic performance of plants under many conditions. We, in fact, used remotely sensed chlorophyll fluorescence from individual leaves to demonstrate that leaves treated with the stress hormone abscisic acid exhibited spatial heterogeneity in stomatal conductance and photosynthesis (Daley et al. 1989).

Because photosynthetic performance is known to decline with salt induced injury we proposed as part of this study that chlorophyll fluorescence should be examined. We suggested that chlorophyll fluorescence measured even from aircraft might be a means of detecting salinity stress in riparian vegetation. Accordingly, we built a laboratory system to measure fluorescence from leaves held under conditions similar to the condition in which they grew. This system included the ability to display and capture images of chlorophyll fluorescence because it is important to know if changes in fluorescence are uniform over a leaf or are heterogeneous as we have shown may occur. A diagram of the system, borrowed from our publication Daley et al. 1989, is provided in Figure 19.

Measurements of chlorophyll fluorescence were made on all species at all salinities in an atmosphere containing 350 micromoles CO_2 per mole of air and with a dew point of 12-15 degrees Celsius. The photosynthetically active photon flux density (PPFD), that is the "photosynthetically active light intensity," was set at 1600 micromoles of 400 -700 nm photons per meter^2 per second. This "light intensity" is the approximate intensity received by the plants in the greenhouse during the mid-day hours. We were surprised to find that

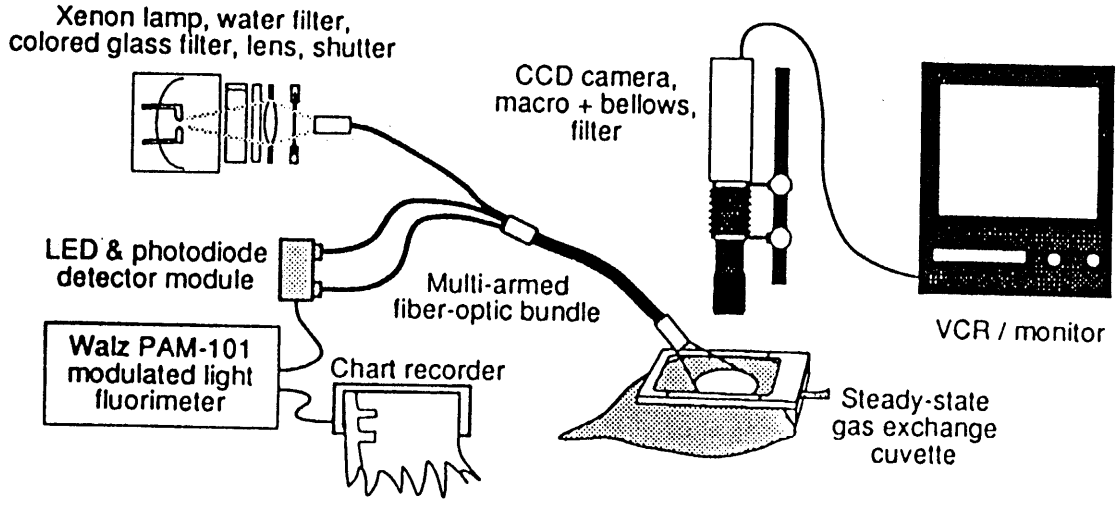


Figure 19.

Image–recording and gas exchange system (CCD = charge coupled device).

at this light level all species at all salinities exhibited a non-photochemical quenching coefficient in the narrow range of 0.91 to 0.96. Since this range is approximately the same as the range of error in the measurement (estimated to be +/- 2 %) we conclude that no differences in chlorophyll fluorescence were detected between species or salinity levels when measured under the light conditions in which the plants were grown.

The above result surprised us because we had anticipated that differences would be found especially between tolerant and intolerant species at higher salinities. We investigated the situation further by examining the fluorescence intensity when photosynthesis was being driven at different levels of photosynthetically active radiation (PPFD). Figure 20 shows the change in photochemical quenching ($qQ = 1 - {}^{q}_{NP}$) as a function of different levels of actinic PPFD for a salt tolerant species *Allenrolfea* and an intolerant species *Tessaria*. As the equation in the last sentence indicates, photochemical quenching (qQ) is the complement of non-photochemical quenching (${}^{q}_{NP}$). The photochemical quenching coefficient is a measure of how efficiently a small increment of light would be used to drive photosynthesis. The figure shows that in all cases at zero light, a small additional amount of light would be used with virtually complete efficiency. The figure also shows that at the light intensity at which they were grown, all plants were approximately equally inefficient at using additional light. That is, all of the plants had adjusted their light capturing systems so that they were fully used or saturated at the growth light intensity. The salt intolerant species, *Tessaria*, at elevated salinity, can be seen to have become light saturated and therefore less efficient at using light at a much lower light intensity in comparison to the other species or treatment. Based on these results, remote sensing of chlorophyll fluorescence would not appear to be a useful technique for detecting salinity stress unless the measurements were conducted when light intensities are well below those which occur for most of the day.

Part 2: ANALYSIS OF SEED GERMINATION

Table 21 indicates percent germination of each species over a four week period. *Allenrolfea* germinated at 0, 1,500 and 6,000 mg/l salinity, but not at higher salinity levels.

Efficiency of Light Use
Species and Salinity Comparison

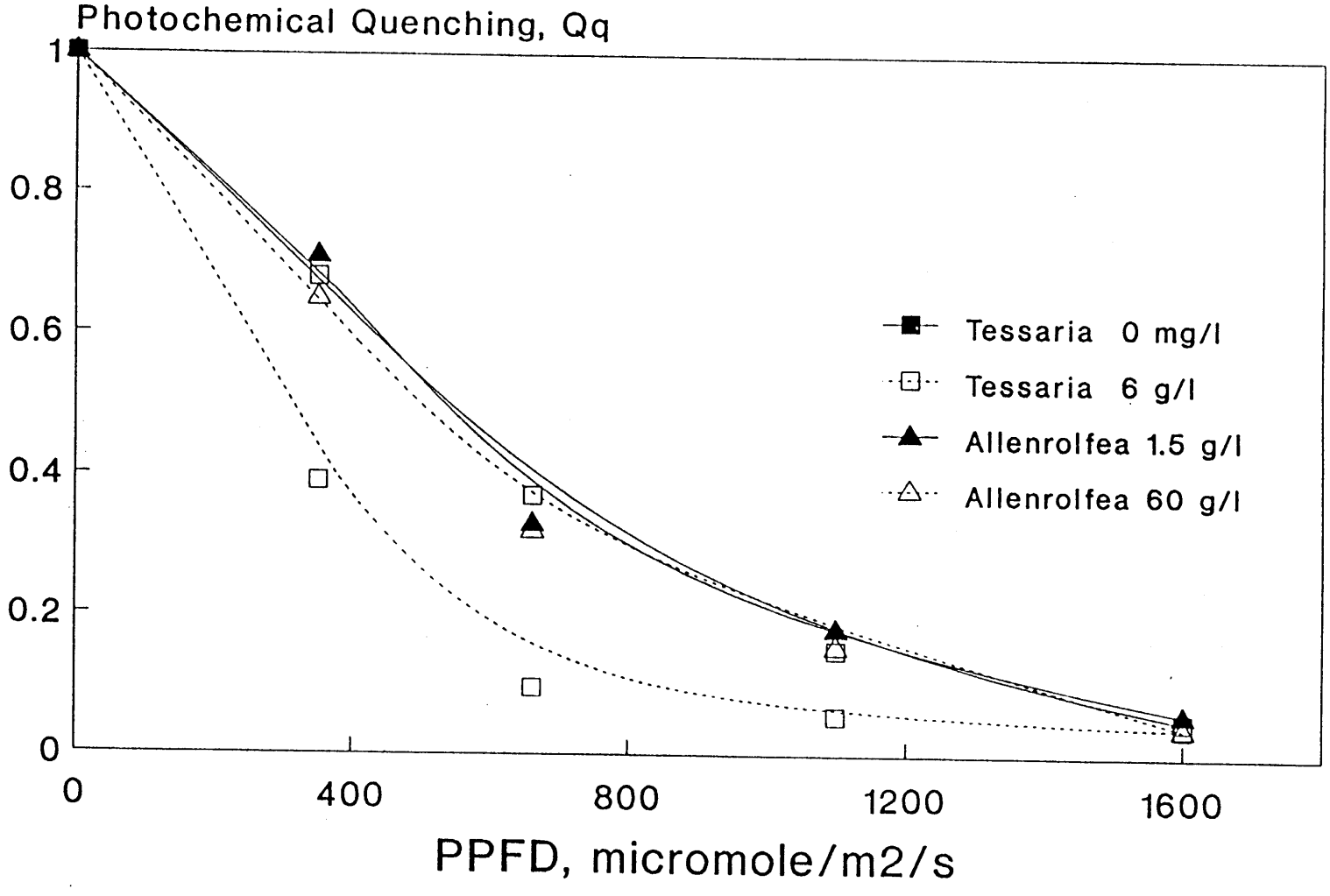


Figure 20

Changes in the photochemical quenching of chlorophyll fluorescence as a function photosynthetically active photon flux density in salinized and control plants of tolerant an non-tolerant species

Table 21. Cumulative percent germination of the eight riparian species at six salinity levels

Salinity (mg/l)	Week-1	Week-2	Week-3	Week-4	Total
Allenrolfea occidentalis					
0	17	17	19	20	20
1,500	35	38	42	42	42
6,000	10	12	15	17	17
18,000	0	0	0	0	0
36,000	0	0	0	0	0
60,000	0	0	0	0	0
Atriplex lentiformis					
0	8	14	22	23	23
1,500	14	22	24	24	24
6,000	3	14	20	21	21
18,000	0	0	0	0	0
36,000	0	0	0	0	0
60,000	0	0	0	0	0
Populus fremontii					
0	44	44	44	44	44
1,500	27	27	27	27	27
6,000	39	39	39	39	39
18,000	0	0	0	0	0
36,000	0	0	0	0	0
60,000	0	0	0	0	0
Prosopis juliflora torreyana					
0	100	100	100	100	100
1,500	100	100	100	100	100
6,000	100	100	100	100	100
18,000	100	100	100	100	100
36,000	0	0	0	0	0
60,000	0	0	0	0	0

Table 21. Cumulative percent germination of the eight riparian species at six salinity levels (cont.)

Salinity (mg/l)	Week-1	Week-2	Week-3	Week-4	Total
Prosopis pubescens					
0	99	99	99	99	99
1,500	98	98	98	98	98
6,000	100	100	100	100	100
18,000	0	0	0	0	0
36,000	0	0	0	0	0
60,000	0	0	0	0	0
Salix gooddingii					
0	67	77	77	83	83
1,500	94	94	96	96	96
6,000	85	88	92	92	92
18,000	2	6	7	7	7
36,000	0	0	0	0	0
60,000					
Tamarix chinensis					
0	5	6	7	7	7
1,500	21	22	22	22	22
6,000	49	52	55	55	55
18,000	11	19	21	21	21
36,000	0	0	0	0	0
60,000	0	0	0	0	0
Tessaria sericea					
0	0	7	15	15	15
1,500	0	0	0	0	0
6,000	0	2	2	2	2
18,000	0	0	0	0	0
36,000	0	0	0	0	0
60,000	0	0	0	0	0

Germination was highest (42 percent) at 1,500 mg/l, and decreased by 50 percent at 0 or 6,000 mg/l. Germination in *Atriplex* was similarly restricted to the three lower salinity levels, and was less than 25 percent in each group.

Populus germination percentages at 0 mg/l, 1,500 mg/l, and 6,000 mg/l, were 44, 27, and 39 percent, respectively, however, germination percentages within the salinity groups varied widely among each replication of 25 seeds. Maximum germination percentages among the replications were 84, 76, and 72 percent, respectively. These wide-ranging data suggest that experimental error may have occurred.

One hundred percent germination of *P. juliflora* seeds was achieved up to and including the 18,000 mg/l salinity level. There was no germination of this species at 36,000 or 60,000 mg/l.

Nearly 100 percent germination of *P. pubescens* was achieved at 0, 1,500, and 6,000 mg/l. *P. pubescens* treated with 18,000 mg/l salt solution was the only seed group to exhibit partial radicle elongation and no cotyledon emergence. Mean radicle length for partially elongated radicles was 3.35 mm (SD = 1.21 mm), which was approximately 75 percent shorter than fully developed radicles in this group.

Results of the germination experiments for *Salix* indicated 83, 96, and 92 percent germination, respectively, at the three lowest salinity levels. Seven percent germination was achieved at 18,000 mg/l. No germination was noted at 36,000 or 60,000 mg/l.

Germination of *Tamarix* occurred at the four lowest salinity levels; 7 percent at 0 mg/l; 22 percent at 1,500 mg/l ; 55 percent at 6,000 mg/l; and 21 percent at 18,000 mg/l. No germination was noted at 36,000 or 60,000 mg/l.

Germination results for *Tessaria* were inconclusive due to extremely low germination percentages.

DISCUSSION

The lower Colorado River region is characterized by extreme aridity, high temperatures, a long growing season, and wide diurnal and annual temperature ranges (Marks 1950). In

many areas, soils are characteristically saline. Historic and recent river manipulations and agricultural conversions have influenced salinity in the river, ground water, and soils, presenting a wide range of saline conditions within the floodplain. Seepage of saline water into floodplains, with subsequent evaporation and capillary rises during the summer months are primary factors contributing to build-up of salinity in floodplain soils along the River (Ohmart et al. 1988; USBR 1989).

High salinity affects plant growth in various ways. It may invoke osmotic desiccation, the mechanism of water exchange from plant cells to the external environment. It can also result in toxicity from the influence of high concentrations of specific ions (Stephenson 1980). Photosynthesis, respiration, protein and nucleic acid metabolism, and enzyme activity are all likely to be affected by salinization (Levitt 1980).

Riparian vegetation species composition along the lower Colorado River is comprised of both halophytes and glycophytes. Halophytes are reportedly capable of growth on substrates containing up to 200,000 mg/l of dissolved solids, although most are restricted to soil salinities of 20,000 to 60,000 mg/l (Strogonov, cited in Levitt 1980). Halophytic plants have developed various mechanisms of salt resistance, including avoidance and tolerance. Many moderately resistant plants use avoidance as a strategy for salt resistance (Levitt 1980). Avoidance includes diverse mechanisms such as salt exclusion, secretion, and dilution. Several of the species tested in this investigation use avoidance strategies to overcome saline environments. For example, members of the genus *Atriplex* exhibit secretion, dilution, and leaf succulence, while *Allenrolfea* exhibits stem succulence. The salt extrusion mechanism localized in salt glands of *Tamarix* is the collecting and excreting cells which non-selectively concentrate salts and excrete the crystals from the leaf surfaces. Some species of *Prosopis* also have salt exclusion mechanisms (Levitt 1980; Kleinkoph and Wallace 1974).

Tolerance is accomplished by osmoregulation, the maintenance of cell turgor through increases in cell solutes to compensate for external osmotic stress. Some species exhibit both avoidance and tolerance mechanisms. Halophytes do not necessarily require excess

salt, but are found in saline environments because they can tolerate conditions that non-halophytes cannot. Their absence from non-saline sites may be a function of competition leading to exclusion by non-halophytes (Ungar 1974).

Glycophytes typically respond adversely to salinity and usually grow well only under non-saline conditions. Glycophytic species are generally affected by either ion excesses in the expanded leaves or by water deficits in expanding tissues (Greenway and Munns 1980). Initial growth responses to salinity include slow leaf growth, and at low salinities, shoot growth may decline while root growth is initially unaffected. Over time, the process of transpiration translocates salts into the growing shoots, eventually resulting in mortality (Munns and Termaat 1986).

The results of this investigation revealed variable growth response to salinity. Some results are interpreted conservatively. For example, correlation analyses, in theory, detect linear trends, however, salt tolerance is not necessarily a linear function. Some species appeared to exhibit greater growth responses at the intermediate salinity levels than at 0 or 60,000 mg/l, and greater response at 0 mg/l than at 60,000 mg/l. These types of responses were indicative of a general rather than absolute trend towards decreased growth with increasing salinity. Therefore, correlations that explain some but not all of the variability among salinity treatments may be explained by this type of non-linear growth response. Also, although many of the correlations involving salinity were statistically significant, observations were made at six fixed levels and the sample size frequently decreased with increasing salinity.

Analysis of morphological growth response provided statistical evidence of species growth response to salinity. However, some possible relationships between growth and salinity were sometimes visually discernable by graphical comparisons but not by statistical analysis. Such relationships could possibly be substantiated by repeating the experiments with a greater sample size and a smaller range of salinity and greater focus on outlier values.

Root-shoot ratios are frequently reliable indicators of growth response. However, the correlation data indicated that since root and shoot biomass responded similarly to salinity, root/shoot ratios did not change. This may be because salinity stress was usually sufficiently high to reduce both root and shoot biomass simultaneously.

Of the three determinate leaves species exhibiting high survival across the range of salinity (*Atriplex*, *P. juliflora*, and *P. pubescens*), leaf area did not provide logical indications of either stress or tolerance. Standard deviations about the mean were large and overlapped extensively between all salinity levels. Mean leaf area of *Tessaria*, however, exhibited measurable decreases with increasing salinity.

Total leaf area for a salt tolerant species (*Atriplex*) and non-salt tolerant species (*Tessaria*) was also examined to determine if this parameter provided a response indicator for salinity. This analysis indicated that within treatment variability was too large to discern differences across treatments. Root/shoot biomass was not a useful indicator of growth response.

Spectral reflectance was generally a useful indicator and predictor of vegetation stress in this investigation. The wavelength position of the chlorophyll red edge is well understood to shift to longer or shorter wavelength positions in response to changing phenologic or physiologic conditions in leaves (Crawford 1986). Our data also indicated drops in the derivative peak of the red edge curve which in all cases was predictive of future morphological stress response.

Spectral reflectance could become a tool for prediction of vegetation stress in the field with the use of remote sensing. The unique spectral features of green vegetation in visible and near infrared wavelength regions can be readily measured and monitored using data acquired from airborne and satellite sensors. Large-scale field use of the spectrophotometry procedures conducted in our laboratories is possible by use of these sensors.

Remotely sensed measurement is rapidly gaining credibility as a predictor of crop stress. The technology presently available is also appropriate for spectral measurement of natural vegetation including riparian associations.

Our purpose in suggesting that this study include measurements of photosynthesis was to determine if this metabolic rate could be used as a management tool. Essentially we thought that there was a possibility that spot measurements of photosynthesis in the field might be a simple, useful integrator and indication of plant and perhaps whole ecosystem condition. Having encountered many difficulties in the benign greenhouse environment we cannot suggest that this measurement would be useful in the field management situations. Obtaining good data and properly interpreting data for the variable conditions in the field is likely to be even more difficult. On the other hand, it would appear that further study of metabolic activity and survival with finer time and salinity steps might reveal time intensity and salinity tolerance threshold relationships. Further studies should be based on more intensive measurements with high accuracy and resolution. For example, photosynthetic measurements should be done with steady-state systems and concentrate on better measurements of smaller samples. There is little value in raising the sample size when that increase in size forces use of techniques which introduce large measurement errors.

In the results section we mentioned that we were surprised by the fact that plants of all species and all salinity treatments showed essentially the same high value of $^{q}_{NP}$. In retrospect and with the experiments showing how $^{q}_{NP}$ changed with light intensity these data make an important point. It is clear that the unsalinized plants and the salinized plants of the tolerant species have invested the resources required to build a light capture system "wisely". It is generally not a good investment strategy to expend resources to maintain the ability to capture light above the light level where the plants normally grow. In the case of the salinized intolerant species a determination can not be made of the cost benefit relationship for the investment in light harvesting systems from the data that we have now. It is known that salinity does damage the function of the Calvin cycle (Dark reactions of photosynthesis). So although the salinized intolerant plants clearly saturates at lower light

intensities they may be obtaining the same benefit per unit invested in light harvesting because the rate of Calvin cycle activity may be the primary limiter of the photosynthetic rate.

Although this kind of economic resource allocation theory has been discussed in ecological circles and applied to stomatal control of water loss we are unaware of so nice a demonstration that this is the case for the metabolic reactions involved in photosynthesis. We plan to follow-up on these findings with submission of research grant proposals to the US Department of Agriculture and to the National Science Foundation.

In the results section we also mentioned the fact that we had collected video images of the chlorophyll fluorescence pattern from leaves. There is great interest with the plant physiological ecology community in the question as to whether photosynthesis and stomatal conductance are ever inhomogeneous across the spatial extent of leaves. Circumstantial evidence from gas exchange measurements has inferred that inhomogeneous conditions can occur. Much of this evidence comes from plants under salt stress. As mentioned, in some of our earlier work we showed that the stress hormone abscisic acid could result in inhomogeneities of stomatal and photosynthetic responses. In none of the hundreds of video images which we collected in this study did we observe a clear indication of these inhomogenieties. We plan to follow-up on the contrast between these and our past findings by submitting another research proposal to the US Department of Agriculture.

The limits of salt tolerance for the species examined during this investigation have been previously reported. The following section provides a synopsis of how our results compare to those of previously conducted field and laboratory investigations.

Atriplex lentiformis. The experimental data suggest that *Atriplex lentiformis* seedlings are generally tolerant of saline conditions and do not express measurable morphological growth decreases at salinities up to 18,000 mg/l. Although growth was reduced at salinities of 36,000 and 60,000 mg/l, there was no mortality in *Atriplex* during the course of this investigation. Germination rates were somewhat lower than originally expected, and lack of

germination beyond 6,000 mg/l was surprising, in view of this species' known salinity tolerance.

Extensive investigations by the University of Arizona on the feasibility of growing *Atriplex* with seawater have demonstrated salt tolerance under seawater concentrations (Glenn and O'Leary 1985). *Atriplex* has also been observed growing under a variety of field conditions. Marks (1950) noted that soil salinities in *Atriplex* communities typically averaged only 1,100 mg/l, while McDonald and Hughs (1968) observed the species growing in soil salinities as high as 12,000 mg/l. Stunted specimens of *Atriplex lentiformis* are present on salt encrusted soils of the Las Vegas Wash in Clark County, Nevada indicating survival and growth under much higher salinities. Revegetation efforts along the Colorado River confirm that seed germination and establishment and growth of this species in moderately saline areas (up to 10,000 mg/l) is feasible (Anderson and Ohmart 1984, in: Kerpez and Smith 1987). In our investigation, lack of seed germination above 6,000 mg/l and overall low germination percentages at and below 6,000 mg/l may be a function of specific complex germination requirements replicable in the laboratory only with a series of dark and light treatments (Young et al. 1980).

Allenrolfea occidentalis. *Allenrolfea* is a widely distributed halophyte and one of the most salt tolerant inland shrubs in the United States (Ungar 1974). The species is present in pure stands on moist saline soils in the Lower Colorado Desert, and is believed to be an indicator of uniformly high salinity throughout the soil profile (Marks 1950). It has been suggested that the species requires some increment of salinity for optimum growth (Ungar 1974). Our data similarly indicate that growth response at moderate salinity levels is greater than at salinities less than 1,500 mg/l or greater than 36,000 mg/l.

Previous investigations of salt tolerance reveal high survival and only minor differences in growth responses of *Allenrolfea* seedlings under various saline conditions. Soil salinity in *Allenrolfea* stands in the Lower Colorado Desert averaged about 19,000 mg/l (Marks 1950). Salinities of up to 30,000 mg/l, with optimal growth at 10,000- 15,000 mg/l have been reported for *Allenrolfea* stands in the Great Salt Lake region (Ungar 1974).

Laboratory seed germination percentages obtained for this investigation appear somewhat low, compared to other results. Early studies by Gold (1939, from Ungar 1974) reported up to 90 percent germination in distilled water with scarification, and little reduction in percentages up to 15,000 mg/l. This discrepancy in our data may have been a function of the pre-treatment process, or because of inherent low germination of the *Allenrolfea* seeds obtained for this study.

Populus fremontii. *Populus* seedlings exhibited low tolerance of saline conditions greater than 1,500 mg/l, while germination percentages approached 70 percent (in one replication) at 6,000 mg/l. Studies of salt tolerance of *Populus* seedlings were not discovered in the literature. Recent investigations on seed germination, however, indicate that optimal germination response in the species was between 0 and 50 millequivalents per liter (meq/l) NaCl (0 to 2,900 mg/l), although higher salinities induced chlorosis and necrosis (Siegel and Brock 1990).

Prosopis juliflora* var. *torreyana and ***Prosopis pubescens.*** Growth response to salinity in the two species of *Prosopis* examined during this investigation indicated fairly uniform survival and growth rates up to 18,000 mg/l. These results are somewhat tentative given the slow growth rates of these species, which may have precluded more definitive growth response.

Field investigations in the southern California desert have indicated that *Prosopis* grows in moderately saline environments. Marks (1950) reported average soil salinities of 4,200 mg/l in mesquite stands. Jarrell and Virginia (1984) reported that *P. glandulosa* var. *torreyana* (synonym for *P. juliflora*) could extract water in soils with salinities approaching 18,000 mg/l, but questioned whether growth could be sustained at these salinity levels. Felker et al. (1981) demonstrated that members of the genus *Prosopis* are tolerant of a regime of salinity up to 36,000 mg/l, however, growth is measurably reduced at higher salinity levels.

Our seed germination responses indicated 100 percent germination of *P. juliflora* at salinities up to 18,000 mg/l, and 0 percent germination at higher salinities. Other

investigators examining salt tolerance in the *Prosopis* genus have indicated variable growth responses. *P. juliflora* seedlings from Senegal, W. Africa exhibited 35, 29, and 26 percent survival rates at salinities of 0, 18,000 and 33,000 mg/l, respectively. Seedlings of *P. glandulosa* var. *glandulosa*, a closely related species from Kingsville, Texas exhibited 100, 46, and 0 percent, respectively (Rhodes and Felker 1988). These authors additionally reported 68 and 0 percent survival of *P. pubescens* seedlings at 0 and 12,000 mg/l, respectively, but acknowledged that mortality could have been a result of some other factor besides salinity.

Salix gooddingii. Mortality in *Salix* above 1,500 mg/l commenced soon after salinization, while individual plants in the 0 and 1,500 mg/l groups exhibited high rates of growth and great vigor. Previous investigations of willow salt tolerance under NaCl concentrations at four levels ranging from 0 to 4 millisemans per centimeter (ms/cm; equivalent to 0-4,000 micromhos per centimeter, roughly equivalent to 0-2,400 mg/l) similarly indicated that members of the *Salix* genus in general are not highly tolerant of salinities of even 1 mS/cm (Crouch and Honeyman 1986).

Salix germination percentages are considered high at the 6,000 mg/l level and highly unusual at the 18,000 mg/l salinity level, given rapid mortality in the seedling stage. Non-halophytic species generally show decreases in percent germination under increased salt concentration (Ayers 1951). Species germination under osmotic stress is not necessarily considered an indication of salt tolerance at other stages of growth (Young et al. 1983).

Tamarix chinensis. Our investigation of the salinity tolerance of *Tamarix* suggested that this species can grow and thrive under various levels of salinity, although growth reductions were noted at 36,000 mg/l and above. These results correlate well with previous laboratory based studies and field investigations of the species.

Tamarix is a dominant and undesirable phreatophyte of Southwestern floodplains. Field investigations have previously suggested that establishment of the species is independent of soil texture, salt, and pH (Ungar, 1974, Campbell and Dick-Peddie 1964).

Field reconnaissance by Marks (1950) indicated average soil salinities of 1,400 mg/l in *Tamarix* associations, which were substantially lower than soils salinities in neighboring *Atriplex*, *Prosopis*, or *Allenrolfea* communities.

Laboratory trials to determine physiological response indicated that *Tamarix* is capable of growth under NaCl concentrations ranging from 10 to 200 meq/l (580 to 11,600 mg/l; Kleinkoph and Wallace 1974). The species appears not to be an obligate halophyte, however, it is known to be tolerant of moderately saline conditions provided that subsurface moisture is available (Ungar 1974).

Tessaria sericea. *Tessaria* growth response to salinities greater than 6,000 mg/l suggested low to moderate salt tolerance, although there was still 100 percent survival by Day-120 at salinities up to 18,000 mg/l. Based on gradually declining growth responses and apparent loss in vigor, it is surmised that *Tessaria* would eventually respond to the 18,000 mg/l salinity level with complete mortality.

Marks (1950) noted that *Pluchea* (synonym = *Tessaria*)-*Tamarix* communities were dependent on groundwater availability, but independent of soil texture. Salinity levels in these communities averaged 1,400 mg/l, however, Marks noted several occurrences of *Tessaria* on more saline soils, and suggested that it is not intolerant of salt, provided that adequate moisture is available for plant growth. McDonald and Hughs (1968) noted maximum soil salinities of about 6,000 mg/l in *Tessaria* stands near Mittry Lake on the lower Colorado River. The experimental data are in agreement with these field observations.

CONCLUSIONS AND RECOMMENDATIONS

The relationship between salinity and growth response is evident to some extent for all species tested across the range of salinity investigated during this study. The implications of these relationships may be useful for revegetation planning strategies along the lower Colorado River, its tributaries, and along the extensive canal systems carrying Colorado River water to urban and agricultural areas in California.

Pioneering revegetation studies by Anderson and Ohmart (1986) indicated high initial success rates for revegetation using Colorado River species. Long-term success of these

efforts has been challenged, since reduced growth or high mortality has occurred in some plantings. These responses are possibly attributable to flooding or drought stress imposed by the effects of temporally and spatially fluctuating soil moisture. The long-term experience of Anderson and Ohmart has been echoed repeatedly in strong statements cautioning against species selections without adequate site analyses (See, for example, Anderson, 1988).

Several types of studies are needed to supplement the present level of knowledge of Sonoran Desert riparian vegetation growth requirements. The relationships between salinity and growth response of *Populus*, *Salix* and *Tessaria* could be discerned through repetitions at salinity levels of 6,000 mg/l and less. Field investigations are also recommended to determine the influence of soil and groundwater salinity, and the effect of groundwater fluctuations on root-zone substrate salinity for all species. A research approach for determining plant-groundwater-soil relationships has been developed for wetlands vegetation in the Las Vegas Wash, an artificially induced tributary of the Colorado River originating in the Las Vegas Valley in Clark County, Nevada (Jackson and Patten 1988). The approach includes the installation of small diameter piezometers for seasonal measurement of groundwater quality and fluctuations. Similar techniques could be adapted for the study of riparian vegetation along the lower Colorado River.

A useful management technique to facilitate Reclamation river monitoring over the short or long term would be implementation of a satellite remote sensing system for measuring plant stress as a function of river operations. The use of laboratory based spectral reflectance measurement for prediction of salt-induced plant stress was described in this study. Systems are currently available to apply these techniques on a field basis. Remotely sensed temporal measurements of vegetation cover combined with spectral reflectance measurements for detection of stress could provide a large-scale view of the effects of operations on natural vegetation and could be a useful mitigation tool for predicting stress prior to the onset of irreversible morphological damage.

Salinity in the Colorado River ecosystem will continue to be a problem for native vegetation growth and revegetation, particularly where river controls and agricultural drainage have indirectly resulted in a mosaic of saline soils. The revegetation success challenge of the nineties will involve informed selection of revegetation sites, prediction of expected variations, and selection of appropriate species.

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Appendix A

Table A-1. Number of data outliers beyond the outer fence for each species, by salinity level (mg/l) and growth variable.
- indicates data collection precluded by mortality.

Atriplex lentiforms	0	1,500	6,000	18,000	36,000	60,000
Root	1	0	1	0	0	0
Shoot	0	0	0	0	0	0
R/S	1	0	0	1	0	1
Day-30	0	0	0	0	0	0
Day-60	0	0	0	0	0	0
Day-90	0	0	0	0	0	0
Day-120	0	0	0	0	0	0

Allenrolfea occidentalis	0	1,500	6,000	18,000	36,000	60,000
Root	0	0	0	0	0	0
Shoot	0	0	0	0	0	0
R/S	0	0	1	2	0	1
Day-30	0	0	0	1	0	1
Day-60	0	0	0	0	0	0
Day-90	0	0	0	0	0	0
Day-120	0	0	0	0	0	0

Populus fremontii	0	1,500	6,000	18,000	36,000	60,000
Root	0	0	0	0	0	0
Shoot	1	0	0	0	?	0
R/S	0	0	0	0	0	0
Day-30	0	0	0	0	0	0
Day-60	0	0	0	0	–	–
Day-90	0	0	0	–	–	–
Day-120	0	0	–	–	–	–

Appendix A, Table A-1. Continued

Prosopis juliflora var. *torreyana*	0	1,500	6,000	18,000	36,000	60,000
Root	0	0	0	0	0	0
Shoot	0	0	1	1	0	0
R/S	0	0	0	0	0	1
Day-30	0	0	0	0	0	0
Day-60	0	0	0	0	0	0
Day-90	1	0	0	0	0	0
Day-120	1	0	0	0	0	0

Prosopis pubescens	0	1,500	6,000	18,000	36,000	60,000
Root	0	0	0	0	0	0
Shoot	1	0	1	1	0	0
R/S	0	0	0	0	0	0
Day-30	0	0	1	0	0	0
Day-60	0	0	0	0	0	0
Day-90	0	0	0	0	0	0
Day-120	0	0	0	1	0	0

Salix gooddingii	0	1,500	6,000	18,000	36,000	60,000
Root	0	0	0	0	0	1
Shoot	0	0	0	0	1	0
R/S	1	0	0	1	1	0
Day-30	0	0	0	1	1	0
Day-60	0	0	0	–	–	–
Day-90	0	0	0	–	–	–
Day-120	0	0	0	–	–	–

Appendix A, Table A-1. Continued

Tamarix chinensis	0	1,500	6,000	18,000	36,000	60,000
Root	0	0	0	0	0	0
Shoot	0	0	1	0	0	0
R/S	0	0	0	0	0	1
Day-30	0	0	0	0	0	0
Day-60	0	0	0	0	0	0
Day-90	0	1	0	0	0	0
Day-120	0	1	0	0	0	0

Tessaria sericea	0	1,500	6,000	18,000	36,000	60,000
Root	1	0	1	0	0	1
Shoot	1	0	0	0	0	0
R/S	1	2	1	0	0	1
Day-30	0	0	0	0	0	0
Day-60	0	0	0	0	0	0
Day-90	0	0	0	0	0	–
Day 120	0	0	0	1	0	–